Report No. FHWA-RD-78-202

HAZARDOUS EFFECTS OF HIGHWAY FEATURES AND ROADSIDE OBJECTS

Vol. 2. Findings

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

September 1978

Final Report

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for

FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D. C. 20590

FOREWORD

This report documents a study on the influence of highway features and roadside objects on single vehicle accidents. It will be of interest to those concerned with the safety of roadway design.

The research was included in the Federally Coordinated Program of Highway Research and Development Project 1K, "Accident Information Analysis." Mrs. Julie Fee is the Project Manager.

The accident data used in this study were collected in six States for a 1-year period between 1975 and 1976. Only non-Interstate, rural highways were considered. Most of these highways were non-divided, two-lane highways with low traffic volumes. Almost 8,000 accidents were included in the study.

Although detailed descriptions of each accident site were obtained, the overall exposure to the various roadway and roadside features in the highway systems contributing these accidents is unknown. Such information would have required a substantial additional effort. Much can be discerned from the data, however, without specific exposure information.

Sufficient copies of this report are being distributed to provide a minimum of one copy to each regional office, division office, and State highway agency. Direct distribution is being made to the division offices.

Charles F. Scheffey

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Director, Office of Research
Federal Highway Administration

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-78-202		

4. Title and Subtitle	5. Report Date
Hazardous Effects of Highway Features and Roadside Objects. Volume 2: Findings	September 1978
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Kenneth Perchonok, Thomas A. Ranney, A. Stephen Baum, Dominic F. Morris, and J. Douglas Eppich	ZR-5564-V-2
9. Performing Organization Name and Address	10. Work Unit No.
Calspan Field Services, Inc. P.O. Box 400 4455 Genesee Street Buffalo, New York 14225	W40/A02
	11. Contract or Grant No.
	DOT-FH-11-8501
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Final Report
Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590	14. Sponsoring Agency Code E0389

15. Supplementary Notes

FHWA Contract Manager: P. Brinkman, HRS-42

16. Abstract

The purpose of this study was to determine hazards in run-off-road accidents. The major data sources were accident data from specially trained state police, and road and roadside data from state files. Data were collected in six states; the sample consisted of almost 8,000 accidents on rural roads.

The findings reflect (1) sample descriptors, (2) factors influencing the occurrence of run-off-road accidents, (3) the characteristics of road departures and factors influencing them, (4) off-road events and factors influencing them, including the effects of offset and clear zones, (5) impact behavior, speed, area of damage, and objects struck, (6) effects of impact characteristics on severity, and (7) effects of driver, road, maneuver, departure, and roadside characteristics on severity.

In addition, there were a number of special studies including the role of impact characteristics in the relationships between severity and ditch depth, border offset, horizontal alignment, and degree of curvature. Also studied were guardrail and culvert impacts, extent of damage and injury relationships, and ADT versus accident rate. Finally, there is a discussion of countermeasures in terms of their classification, costs, needs, and current practice.

This report will serve best as a documentation of road and roadside factors influencing vehicle behavior and accident severity. Volume 1 contains a literature review, and the methodology for the data collection and preparation for analysis. Volume 2 contains the study results.

17. Key Words	18. Distribution Statement
Accident Severity, Countermeasures, Highway Hazards, Roadside Features, Run-Off-Road Accidents, Rural Accidents, Single Vehicle Accidents	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None	332	

Form DOT F 1700.7 (8-69)

Metric Conversion

Several customary units appear in the text of this report. Generally, it is the policy of FHWA to express measurements in both customary and SI units. The purpose of this policy is to provide an orderly transition to the use of SI exclusively. For this particular report, however, it was decided that dualization was not warranted because of the additional cost and delay in making this research available. Instead, the following conversion table is included.

To convert	To	
ft	m	Multiply by 0.348*
mi	km	Multiply by 1.609
mi/h	km/h	Multiply by 1.609
Accidents/MVM	accidents/MVkm	Multiply by 0.6214

*denotes exact conversion factor

The Federal Highway Administration recognizes the "Standard for Metric Practice", E380 of the American Society for Testing and Materials, as the authority for SI usage.

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1. SAMPLE DESCRIPTORS

In order to provide a context within which the results of the current study can be usefully interpreted, a set of frequency distributions describing the data sample is presented. Included in this section are frequency distributions in which accident locations are characterized in terms of roadway type, roadway alignment, operating characteristics, vehicle type, ambient conditions, and driver characteristics. Discussion of the causal implications associated with several of the univariate distributions are deferred to a subsequent section.

1.1 Roadway Type

Data for the current study were collected on both freeway and non-freeway types of roads. Overall, approximately 85 percent of the data were collected on undivided roads, with the remainder having been collected on divided or separated roadways. Presented in Table 1-1 are the frequencies and proportions of accident locations categorized according to roadway type and number of through lanes in the traveled direction.

As indicated by the proportions, 99 percent of the undivided accident roads had one through lane in the travel direction. Ninety-eight percent of the divided roadways on which accidents occurred had two lanes in the travel direction.

TABLE 1-1 NUMBER OF THROUGH LANES BY ROADWAY TYPE

	Number of Through Lanes								Total	
	1		2		3		Unknown			
	N	%	N	%	N	%	N	%	N	%
Undivided	6,651	98.9	72	1.1	-	-	1	0.0	6,724	100.0
Divided	13	1.1	1,113	98.4	5	0.4	-	-	1,131	100.0
Separated Roadway	1	2.0	46	93.9	2	4.1	-	-	49	100.0
Unknown	24	35.3	-	-	-	-	44	64.7	68	100.0
TOTAL	6,689	83.9	1,231	15.4	7	0.1	45	0.6	7,972	100.0

One of the primary operating characteristics describing a roadway system is the average daily traffic volume (ADT). Table 1-2 presents the distribution of accident locations categorized by the ADT. In this table, unknowns are shown adjacent to the low volume roads. This is because of the high likelihood that roads with unknown ADT are actually low volume roads with ADT of less than 400. Accident locations are also categorized according to the two primary types of roadway represented in the sample.

TABLE 1-2 ADT BY ROADWAY TYPE

	Undivided		Divided & Separated		Roadway Type Unknown		Total	
ADT	N	%	N	%	N	%	N	%
Unknown	1,957	29.1	45	3.8	49	72.1	2,051	25.7
1-399	353	5.2	0	0.0	1	1.5	354	4.4
400-1499	1,921	28.6	37	3.1	6	8.8	1,964	24.6
1500-2999	1,165	17.3	119	10.1	6	8.8	1,290	16.2
3000-9999	1,195	17.8	682	57.8	3	4.4	1,880	23.6
> 10,000	133	2.0	297	25.2	3	4.4	433	5.4
TOTAL	6,724	100.0	1,180	100.0	68	100.0	7,972	100.0

Combining the unknowns with the low volume roads, it is apparent that 30 percent of the accidents occurred on low volume roads. Forty-one percent of the sampled accidents occurred on roads with ADT between 400 and 3,000. The proportions for undivided roads are essentially the same as the overall proportions, as would be expected. For divided and separated roadways, 83 percent of the involvements occurred on roads with ADT greater than or equal to 3,000. The relatively high proportion of unknowns associated with undivided roads but not divided ones is consistent with the assumption that the majority of unknowns were low volume roads.

The distribution of accident locations categorized by pavement surface type is presented in Table 1-3.

TABLE 1-3 PAVEMENT SURFACE TYPE

	N	%
Bituminous surface-treated	500	6.7
Mixed Bituminous	4,067	54.1
Bituminous Concrete	2,595	34.5
Portland Cement Concrete	352	4.7
TOTAL	7,514	100.0

Of the four pavement types represented in the table, mixed bituminous and bituminous concrete surfaces accounted for 89 percent of the overall involvements. The remaining 11 percent of the accident involvements were split between bituminous surface-treated and Portland Cement concrete. Concerning the individual surface types, the bituminous surface-treated is the crudest surface, and is generally associated with low volume county roads. This surface is prone to chuck holes and general disintegration. These roads are typically characterized by narrow lanes and shoulders. The mixed bituminous surface is generally associated with medium volume state roads, and is of better quality and composition control than the surface-treated roads. As indicated in the table, 54 percent of the sampled involvements occurred on this type of surface.

Bituminous concrete is the best grade of concrete and asphalt and is used on newer state roads and on interstates. It is the most flexible surface and provides a smooth ride. Before the increase in the price of petroleum products, this surface was considerably less expensive to apply than Portland Cement concrete. Portland Cement concrete is the highest grade of concrete and is used primarily on interstate roads. This surface is rigid and is more durable than asphalt. Both of these surface types are widely used on higher volume roads and are associated with wider lanes and shoulders.

1.2 Road Alignment

Table 1-4 presents the distribution of accident locations categorized by the horizontal alignment. As indicated, 57 percent of the accidents occurred on straight roads, 39 percent on curves.

TABLE 1-4 HORIZONTAL ALIGNMENT

	N	%
Tangent	4,554	57.1
Left Curve	1,869	23.4
Right Curve	1,263	15.8
Unknown	286	3.6
TOTAL	7,972	100.0

Degree of curvature and length of curve were recorded for horizontal curves. The distribution of accident locations categorized by these two variables is presented in Table 1-5. Only accidents which occurred on horizontal curves are included in this table.

The total column presents the univariate frequencies for the categories of degree of curvature. As indicated, for the curves of known

TABLE 1-5 LENGTH OF CURVE BY DEGREE OF CURVATURE

Degree of Curvature	Length of Curve (hundreds of feet) 1-2 N	1-2 %	3-4 N	3-4 %	5-6 N	5-6 %	7-10 N	7-10 %	11-15 N	11-15 %	16-97 N	16-97 %	Total Known N	Total Known %	Unk.	Total N	Total %
0-4	23	3.3	69	10.0	70	10.1	135	19.5	123	17.8	271	39.2	691	100.0	504	1,195	51.4
4-8	46	13.0	89	25.2	70	19.8	88	24.9	43	12.2	17	4.8	353	100.0	239	592	25.5
8-12	51	25.5	83	41.5	27	13.5	25	12.5	8	4.0	6	3.0	200	100.0	114	314	13.5
12+	58	44.3	38	29.0	25	19.1	7	5.3	2	1.5	1	0.8	131	100.0	94	225	9.7
Total Known	178		279		192		255		176		295		1,375		951	2,326	100.0
Unknown	37		10		3		3		3		4		60		746	806	
TOTAL	215	15.0	289	20.1	195	13.6	258	18.0	179	12.5	299	20.8	1,435	100.0	1,697	3,132	

radius, slightly more than half occurred on curves of less than four degrees. The bottom row of the table presents the univariate frequencies for length of curve. According to the proportions, the median curve length in the sample is approximately 600 feet.

There was a negative correlation between degree and length of curve. Specifically, the median length was in the 1,100 to 1,500 foot range for the shallow (up to four degree) curves. For the successively sharper curves, the median lengths were in the ranges of 500 to 600 feet, 300 to 400 feet, and just above 300 feet, respectively.

Table 1-6 presents the distribution of accident locations categorized by the vertical alignment at the accident location.

TABLE 1-6 VERTICAL ALIGNMENT

	N	%
Level	2,001	34.6
Upgrade	943	16.3
Downgrade	1,533	26.5
Up on Crest	373	6.5
Down on Crest	461	8.0
Up on Sag	258	4.5
Down on Sag	211	3.7
Total Known	5,780	100.0
Unknown	2,192	-
TOTAL	7,972	-

Overall, 35 percent of the accidents with known vertical alignment occurred on level roads, 43 percent on upgrades and downgrades, and 24 percent on vertical curves.

1.3 Vehicle Type

The sample included both automobile and truck accidents. The distribution of vehicle type is presented in Table 1-7.

TABLE 1-7 VEHICLE TYPE

	N	%	Overall %
Auto:			
Sports, Subcompact	1,124	20.6	14.1
Compact	1,255	23.0	15.7
Intermediate	1,203	22.1	15.1
Full Size, Luxury	1,641	30.1	20.6
Unknown Auto	228	4.2	2.9
Total Auto	5,451	100.0	68.4
Utility Vehicle (Jeep Type)	187	-	2.3
Truck:			
Light	1,338	57.8	16.8
Van/Motor Home	285	12.3	3.6
Heavy, Special	650	28.1	8.2
Unknown Truck	40	1.7	0.5
Total Truck	2,313	100.0	29.0
Recreational Vehicle	7		0.1
Other/Unknown	14		0.2
TOTAL	7,972		100.0

In this table, there are two columns of proportions. The first presents proportions within vehicle type. The second column represents proportions relative to all involved vehicle types. For example, 68 percent of the accidents involved automobiles and 29 percent involved trucks. Twenty-one percent of the automobiles were sports or subcompact vehicles.

1.4 Ambient Conditions

In addition to characteristics of the accident roadways, ambient conditions, such as lighting and weather, were coded as part of the description of each accident. The distribution of accident categorized by light condition is presented in Table 1-8.

TABLE 1-8 LIGHT CONDITION

	N	%
Day	4,034	50.6
Dawn or Dusk	347	4.4
Dark, Lights	115	1.4
Dark, No Lights	2,494	31.3
Dark, Unknown Lights	956	12.0
Not Reported	26	0.3
TOTAL	7,972	100.0

As is readily apparent, the two predominant light conditions were daylight and dark without lights. The third most frequent light condition was nighttime where road lighting was unknown. This was due to the absence of a road lighting information requirement in the accident report form for two states. Because of the relative proportions of nighttime accidents with and without lighting, it is likely that the majority of the nighttime accidents with unknown lighting actually involved unlighted roads.

Table 1-9 presents the distribution of accident locations categorized by road condition at the time of the accident.

TABLE 1-9 ROAD CONDITIONS

	N	%
Dry	6,303	79.1
Wet	932	11.7
Wintry	664	8.3
Unknown	73	0.9
TOTAL	7,972	100.0

As indicated, 79 percent of the sampled accidents occurred on dry roads. Regarding wintry conditions, the relative frequency would, of course, vary considerably from state to state depending on climate.

Information concerning road conditions is of importance for determining vehicle-handling problems. For the purpose of determining visibility restrictions at the time of the accident, weather conditions were also recorded. Where it was possible to determine, weather factors were indicated as having been contributory to the occurrence of the accident. The results are in Table 1-10.

TABLE 1-10 WEATHER CONDITIONS

	Overall		Contributory	
	N	%	N	%
Clear	6,618	83.0	0	0.0
High Winds	148	1.9	148	46.0
Rain	700	8.8	100	31.1
Snow	263	3.3	41	12.7
Fog	151	1.9	26	8.1
Other, Unknown	92	1.2	7	2.2
TOTAL	7,972	100.0	322	100.0

Overall, 83 percent of the accidents occurred in clear weather. Nine percent occurred in the rain and three percent in snow. Fog and high winds were each specified for two percent of the accidents. The weather was reported as contributing to the occurrence of four percent of the accidents. In almost one-half of these, the problem was high winds; note that this was not reported unless it was a possible problem. Following high winds, in order of decreasing frequency, were rain, snow, and fog.

1.5 Driver Characteristics

Because the primary emphasis of this study was on highway features, the amount of information pertaining to the driver was relatively limited. The available information pertained to the driver's physical condition at the time of the accident and to the accident trip.

One of the primary indications of driver condition is whether the driver was noticeably tired or asleep at the time of the accident. Results are in Table 1-11. Unfortunately in the current sample, this was largely not

reported. Of the thirty-seven percent of the accidents for which driver fatigue was reported, approximately a third were reported as having been asleep at the time of the accident. A small percentage of drivers were reported as having been tired, but not asleep. The remaining two-thirds were reported as not asleep or tired at the time of the accident.

TABLE 1-11 DRIVER FATIGUE

	N	%
Normal	1,904	23.9
Tired	120	1.5
Asleep	911	11.4
Other, Unknown	5,037	63.2
TOTAL	7,972	100.0

A second driver condition for which the proportion of reported cases was much higher was drinking status. The distribution of drinking status is presented in Table 1-12.

TABLE 1-12 DRIVER DRINKING STATUS

	N	%
Not Drinking	3,651	45.8
Had Been Drinking	840	10.5
Had Been Drinking - Contributory	727	9.1
Cited for DWI	913	11.5
Not Reported	1,841	23.1
TOTAL	7,972	100.0

As indicated, in 32 percent of the accidents, the driver was reported to have been drinking. If one assumed that a citation for driving while intoxicated (DWI) implies that the drinking status of the driver was causally related to the generation of the accident, at least 21 percent of the accidents could be at least partly attributed to drinking.

Of all violations cited by the police, driving while intoxicated was the most frequent. Other moving violations for which drivers were cited are given in Table 1-13. Of these, the most frequent was speeding, followed by reckless driving.

TABLE 1-13 MOVING VIOLATIONS

	N	%
None Cited	6,898	86.5
High Speed	624	7.8
Reckless Driving	250	3.1
Illegal Passing	9	0.1
Speed and Reckless	5	0.1
Speed and Passing	2	0.0
Reckless and Passing	1	0.0
Speed, Reckless, and Passing	0	0.0
Other	183	2.3
TOTAL	7,972	100.0

The accident trip was described in terms of the origin and intended destinations. The distribution of trip plan is shown in Table 1-14.

TABLE 1-14 TRIP PLAN

	N	%
Home to Work	524	6.6
Work to Home	575	7.2
Business - Local	647	8.1
Business - Long Distance	792	9.9
Shopping	221	2.8
Social - Recreational	3,387	42.5
Touring	585	7.3
Unknown/Other	1,241	15.6
TOTAL	7,972	100.0

As is apparent, the single most frequent type of trip was social or recreational. The touring category refers to cross-country vacation type travel.

Where possible, the experience of the driver with the accident road was recorded. The distribution of route familiarity is presented in Table 1-15.

TABLE 1-15 ROUTE FAMILIARITY

How often traveled?	N	%
Daily	1,965	24.6
1+/Week	1,590	19.9
1+/Month	1,030	12.9
Rarely	1,250	15.7
First Time	787	9.9
Unknown	1,350	16.9
TOTAL	7,972	100.0

Almost half of the accidents occurred on roads which were driven at least once per week. For approximately one-quarter of the accidents, the driver had little or no experience with the road.

1.6 Causal Variables

One of the variables constructed to characterize predeparture driver/vehicle behavior was maneuver. Maneuvers consist of three major categories:

1) Road tracking problems
2) Turns
3) Responses to external influence

The first category includes accidents initiated by a loss of control; these behaviors were usually indicated by tire marks on the road and/or police-reported skidding or sliding. This category also includes accidents in which the vehicle first departed the road with no indication of a control failure, corrective response, or other contributing circumstance.

The second category includes road departures associated with turns at intersections. A wide turn reflects what amounts to an insufficient steering input. An example of a short (right) turn is departing the (right) side of the road just before entering the intersection. A protracted turn is one in which the steering input is maintained even after the intended turn was completed.

The third category implies the existence of an external factor, such as another vehicle or an animal. For these classifications, the vehicle departure was the result of an attempt to avoid another potential problem. Table 1-16 presents the distribution of maneuvers prior to departing the road.

TABLE 1-16 MANEUVER

		N	%
Attempted to Stay on Road or Failed to do so	Control failure or attempted correction	4,011	50.3
	No corrective response	2,202	27.6
	CF or NCR	841	10.5
	Turn: wide	105	1.3
	Turn: short	9	0.1
	Turn: protracted	13	0.2
Response to External Influence	Path ends	11	0.1
	Traffic control	25	0.3
	Vehicle ahead (Opposite Direction)	226	2.8
	Vehicle ahead (Same Direction)	187	2.3
	Vehicle to side	42	0.5
	Intersecting vehicle	28	0.4
	Animal	185	2.3
	Other or Unknown Type	56	0.7
	Other or Unknown Type	31	0.4
	TOTAL	7,972	100.0

As indicated in the table, 50 percent of the accidents involved either a control failure or attempted correction. Another 28 percent involved no apparent corrective response. In eleven percent of the accidents, this distinction above could not be made. Thus, almost 90 percent of the accidents involved road tracking problems.

The small proportion of accidents involving a response to an external influence derives from the nature of the sampled accidents; that is, single vehicle accidents. In total, 760 (10%) of the 7,972 accidents involved a response to an external influence. The primary external influences were vehicles and animals. Five percent (413) of the accidents involved a vehicle ahead.

An induced control failure was coded when a loss of control was thought to be at least partially attributable to road surface conditions. Table 1-17 shows that one percent of the accidents were due, in part, to rough road surfaces. Eleven percent were associated with ice or snow (or perhaps oil, mud, etc.) covering the road surface.

TABLE 1-17 INDUCED CONTROL FAILURES (ICF)

	N	%
Rough road	42	0.5
Road surface cover	834	10.5
Other or Unknown Type	4	0.1
Unknown if ICF	94	1.2
No ICF	6,998	87.8
TOTAL	7,972	100.0

Table 1-18 presents the distribution of malfunctions; that is, whether a vehicle or driver breakdown was reported as contributory to the generation of the accident.

TABLE 1-18 MALFUNCTION

	N	%
Vehicle Breakdown	436	5.5
Driver Breakdown	951	11.9
None Reported	6,585	82.6
TOTAL	7,972	100.0

Breakdowns refer to sudden changes in the driver or vehicle rendering further travel unreasonable. Examples are flat tires, brakeline failures, falling asleep, and heart attacks, but not bald tires, worn brakes, or drinking. The results show that driver breakdowns were reported twice as often as vehicle breakdowns in single vehicle accidents.

1.7 Summary of Sample Descriptors

1. Approximately 85 percent of the accidents occurred on undivided roads; almost all of which were two-lane roads.

2. Assuming unknown ADTs imply low volume, 30 percent of the sampled accidents occurred on low volume (ADT less than 400) roads.

3. Fifty-seven percent of the accidents occurred on straight roads, 39 percent on curves. In general, sharp curves were short and shallow curves were long.

4. Thirty-five percent of the accidents occurred on level roads, 43 percent occurred on tangent grades.

5. Sixty-nine percent of the accident vehicles were automobiles, 29 percent were trucks, and two percent were utility vehicles.

6. Half the accidents occurred in daylight, 44 percent at night. Unlighted roads were associated with the majority of nighttime accidents.

7. Seventy-nine percent of the accidents occurred on dry roads, 12 percent on wet roads, 8 percent on roads with winter covering (ice, snow, slush, etc.).

8. Fifteen percent of the accidents occurred during inclement weather. Weather was reported as contributory for four percent of the accidents.

9. Approximately 13 percent of the drivers were noted as having been tired or asleep at the time of the accident. This variable, however, was widely not reported.

10. Thirty-two percent of the accident drivers were reported to have been drinking. Twelve percent were cited for DWI.

11. Fourteen percent of the drivers were cited for violations of the rules of the road.

12. Concerning the purpose of the trip, 43 percent were social-recreational.

13. Almost one-half of the drivers were quite familiar with the accident road.

14. Predeparture maneuvers consisted of attempts to stay on the road (control failure) (50%) or failures to do so (28%), and responses to an external influence (10%). Eleven percent of the accidents involved control failures induced by either rough road or road surface cover (e.g., snow or ice).

15. Five percent of the accidents involved a reported vehicle breakdown. Twelve percent involved a reported driver breakdown.

2. PREDEPARTURE FACTORS RELATED TO ACCIDENT OCCURRENCE

In addition to providing background information concerning the nature of the sample, some of the distributions provide information pertaining to factors influencing accident occurrence. The interpretation of a particular variable as a factor influencing accident occurrence depends upon the specification of a priori expectations about the distribution in question. In so doing, the requirements for corresponding exposure data are bypassed. For example, considering horizontal alignment at the accident location, since every left curve in one travel direction is a right curve in the opposing travel direction, overall exposure to the left and right curves is approximately equal. The a priori expectation would be that if direction of curve was not a factor influencing the occurrence of accidents, then the proportion of accidents occurring on the left and right curves should be approximately equal. A higher proportion of incidence on curves of one direction relative to the other direction would therefore suggest that direction of curve somehow influences the occurrence of accidents.

Unfortunately, the number of variables for which such "exposure-free" expectations can be formulated is minimal. For example, in comparing the proportions of accidents which occurred on sharp versus shallow horizontal curves, there is no expected matching which can be established. Specifically, there is no reason to believe that the proportion of shallow curves in a particular system of roads is in any way related to the proportion of sharp curves in the same system. For this particular variable, it may well be the case that a disproportionate number of accidents on one type of curve simply reflects the type of curve most often found in the roadway system. In order to make any conclusion about the relation between curve type and accident occurrence, the appropriate exposure information documenting the types of curves in the system under consideration would be required. In general, this type of information was not available for use in the current study, as the collection of such data would require an effort of at least the same magnitude as that required to collect the accident data.

It is often the case that for variables with no a priori expectations concerning the nature of the distribution, combination with an appropriate second variable will allow for the specification of expectations concerning the interactions between the two variables. For example, roadway characteristic descriptors when combined with contextual (weather, road condition, etc.) or driver/vehicle behavioral (maneuver, departure attitude) variables often allow conclusions concerning accident occurrence to be made. The purpose of the current section, then, is to selectively examine the variables which provide information about the "cause" of the accident.

2.1 Horizontal Alignment

As previously indicated, concerning the horizontal alignment at the accident location, 57 percent of the accidents occurred on straight roads, 39 percent on curves. Of importance for the determination of accident cause, is the difference in proportions of left and right curves. As discussed above, considering only accidents which occurred on horizontal curves, since each left curve in one travel direction is a right curve in the opposing travel direction, it would be expected that if direction of curve were not of causal importance, then the proportion of accidents occurring on left and right curves should be approximately equal. The fact that proportionately more accidents occurred on left curves than on right curves, indicates that curve direction is somehow related to accident causation. In an attempt to determine more specifically what factors associated with curve direction were of importance for determining accident occurrence, the remainder of this section is devoted to examining variables which interact with curve direction.

In the current study, data were collected on two types of roadway, divided and undivided roads. In an attempt to determine the nature of the difference in proportions for left versus right curves, the distribution of

horizontal alignment at the accident location was examined separately for divided and undivided roads. Table 2-1 presents the results.*

TABLE 2-1 HORIZONTAL ALIGNMENT BY ROADWAY TYPE

Horizontal Alignment	Undivided		Divided	
	N	%	N	%
Tangent	3,663	56.3	847	76.4
Left Curve	1,751	26.9	111	10.0
Right Curve	1,089	16.7	151	13.6
TOTAL	6,503	100.0	1,109	100.0

As indicated in the table, the overinvolvement of left curves derived from accidents on undivided roads. Considering accidents which occurred on divided highways, only 24 percent occurred on curves. Of these, right curves were reported somewhat more frequently than left curves.

In a separate analysis, the effect of traffic on the horizontal alignment at the accident location was examined by looking at the distribution of horizontal alignments for various ADT classifications. Considering only undivided roadways, the largest proportion of accidents occurring on left curves were associated with lowest ADT roads. This suggests, although indirectly, that it was not the oncoming traffic which is a difficulty for drivers negotiating left curves.

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* Most of the tables in the remainder of this report are multivariate in form. Thus, the practice of including unknowns would be cumbersome and would distract from the essential information. Therefore, in most instances, the unknowns do not appear. As a result, the total number of observations will vary from table to table.

In another attempt to determine what features of left curves might account for the higher incidence, the interaction of curve direction and degree of curvature was examined. A two-way chi-square indicated no significant interaction between the two variables, suggesting that degree of curvature was not related to the proportional difference between left and right curves.

Road conditions were cross-tabulated with horizontal alignment. The results are given in Table 2-2. Only data from the three states with a significant amount of snowfall were included. There was a statistically significant interaction between alignment and road condition (X_4^2 = 26.58*), but the effect was almost totally due to dry and wet conditions versus winter conditions (X_2^2 = 25.65).

TABLE 2-2 HORIZONTAL ALIGNMENT BY ROAD CONDITION

(Wyoming, South Dakota, Maine)

Road Condition	Tangent		Left Curve		Right Curve		Total	
	N	%	N	%	N	%	N	%
Dry	1,061	62.3	366	21.5	276	16.2	1,703	100.0
Wet	143	60.6	49	20.8	44	18.6	236	100.0
Winter	455	72.8	85	13.6	85	13.6	625	100.0
TOTAL	1,659	64.7	500	19.5	405	15.8	2,564	100.0

The results show that the effect of wintry surfaces was to increase the proportion of accidents on tangents and decrease that on curves. This suggests that there was an effective increase in driver caution on slippery curves. It can also be seen that while there were relatively more left curve accidents (versus right) on dry roads, the difference was diminished on wet roads and non-existent on icy or snowy roads.

* All testing was done for two-sided hypotheses at the 0.05 level.

In an attempt to determine if a significant number of drivers missed curves because they could not see them, the interaction of horizontal alignment and light condition was examined. No differences were found among the various light conditions in the proportions of accidents occurring on horizontal curves versus straight roads.

In a similar manner, the proportions of accidents occurring on straight and curved roads were compared for the various categories of driver route familiarity in Table 2-3. The smallest proportion of horizontal curves was associated with the set of drivers who traveled the accident road daily. Furthermore, the largest proportion of occurrences on curved roads was associated with drivers who had never driven the road before. This interaction was tested and found to be statistically significant ($X^2_8 = 21.71$).

TABLE 2-3 HORIZONTAL ALIGNMENT BY ROUTE FAMILARITY

	Tangent		Left Curve		Right Curve		Total	
Familiarity	N	%	N	%	N	%	N	%
Daily	1,158	61.1	443	23.4	293	15.5	1,894	100.0
1+ Week	894	58.7	393	25.8	237	15.6	1,524	100.0
1+ Month	610	61.0	219	21.9	171	17.1	1,000	100.0
Rarely	688	56.7	316	26.0	210	17.3	1,214	100.0
First Time	407	53.6	204	26.8	149	19.6	760	100.0

Driver drinking status was found to interact significantly ($X^2_6 = 34.17$) with horizontal alignment. The results are in Table 2-4. Drivers reported as not drinking prior to the accident were less often involved in a departure from a curved road. Drinking drivers were proportionately more likely to have departed from a horizontal curve. There was no difference between the three drinking conditions (DWI, had been drinking, etc.) in this regard.

TABLE 2-4 HORIZONTAL ALIGNMENT BY DRINKING STATUS

Drinking Status	Tangent		Left Curve		Right Curve		Total	
	N	%	N	%	N	%	N	%
No	2,143	60.6	809	22.9	583	16.5	3,535	100.0
HBD	429	53.4	222	27.6	152	18.9	803	100.0
HBD - Contributory	372	53.6	202	29.1	120	17.3	694	100.0
DWI	470	54.2	256	29.5	141	16.3	867	100.0

In summary, the overrepresentation of left curves relative to right curves existed only for undivided roads. This difference was nonexistent for wintry road surfaces. It was also found that the proportion of accidents on curves decreased on wintry surfaces and increased for drinking drivers and drivers without previous experience with the road.

2.2 Vertical Alignment

Accident locations were also characterized in terms of the vertical alignment. The frequency distribution of accident locations categorized according to the vertical alignment is presented in Table 2-5. (This table was previously presented in the discussion of sample descriptors.)

TABLE 2-5 VERTICAL ALIGNMENT AT ACCIDENT LOCATION

Vertical Alignment	N	%
Level	2,001	34.6
Upgrade	943	16.3
Downgrade	1,533	26.5
Up on Crest	373	6.5
Down on Crest	461	8.0
Up on Sag	258	4.5
Down on Sag	211	3.7
Total Known	5,780	100.0
Unknown	2,192	-
TOTAL	7,972	-

Because every upgrade in one travel direction exists as a downgrade in the other travel direction, differences in proportion of occurrence between upgrades and downgrades have causal implications. As is apparent, accidents occurred on downgrades proportionately more often than on upgrades. The implication is that downgrades were causally related to accident occurrence.

Although not matched for exposure, the proportions indicate that crests were more often the location of accidents than were sags.

The overrepresentation of downgrades relative to upgrades was associated with undivided roads. The distribution of vertical alignments separated into undivided and divided roads is presented in Table 2-6.

TABLE 2-6 VERTICAL ALIGNMENT BY ROADWAY TYPE

	Undivided		Divided & Separate Roads	
	N	%	N	%
Level	1,775	37.6	221	21.5
Upgrade	675	14.3	259	25.2
Downgrade	1,267	26.8	260	25.3
Up on Crest	297	6.3	75	7.3
Down on Crest	371	7.9	89	8.7
Up on Sag	188	4.0	66	6.4
Down on Sag	153	3.2	58	5.6
TOTAL	4,726	100.0	1,028	100.0

On divided roads, the proportion of accident occurrences associated with upgrades was identical to that associated with downgrades. Furthermore, relative to the undivided sample, proportionately fewer of the divided road accidents occurred on level roads. It might also be noted that on undivided roads, the proportion of accidents on downgrades was almost twice that of upgrades.

As discussed in the literature review, horizontal and vertical alignment have been found to interact in previous accident studies. Specifically, horizontal curves on grades have been cited as being overrepresented as locations for accidents. Table 2-7 presents horizontal alignment within vertical alignment categories.

TABLE 2-7 HORIZONTAL ALIGNMENT BY VERTICAL ALIGNMENT

	Horizontal							
	Tangent		LC		RC		Total	
Vertical	N	%	N	%	N	%	N	%
Level	1,484	74.4	305	15.3	206	10.3	1,995	100.0
Upgrade	576	61.5	205	21.9	155	16.6	936	100.0
Downgrade	822	53.8	435	28.5	270	17.7	1,527	100.0
Up on Crest	206	55.2	115	30.8	52	13.9	373	100.0
Down on Crest	218	47.7	142	31.1	97	21.2	457	100.0
Up on Sag	163	63.2	60	23.3	35	13.6	258	100.0
Down on Sag	130	61.6	51	24.2	30	14.2	211	100.0

Previous results had implicated left curves as being overrepresented relative to right curves. Table 2-7 shows that this was true for each of the vertical alignment categories. In addition, the results show a five percent higher proportion of left curves on level roads and on upgrades, but a minimum of a ten percent differential for any other vertical alignment categories. This interaction, however, was not statistically significant ($X_1^2 = 3.21$). Thus, there were proportionately more accidents on left curves than right for each vertical alignment category, but the degree of overrepresentation did not vary significantly among those categories.

Next, ignoring the direction of curvature and focusing on straight roads versus curves, the proportion of accidents on curves varied significantly as a function of vertical alignment ($X_6^2 = 220.86$). On level roads, 26 percent (15.3 + 10.3) of the accidents occurred on horizontal curves. For every other vertical alignment category, the proportion of accidents on horizontal curves was greater than 26 percent. On upgrades, the proportion was 38 percent, and

on downgrades it was 46 percent. The vertical alignment category with the highest proportion of accidents on curves was down on crests; the proportion was 52 percent. The major sources of the obtained chi-square value were: (1) the underrepresentation of curves on level roads (X_1^2 = 183.58); (2) the overrepresentation of curves on down versus upgrades (X_1^2 = 14.05); and (3) the overrepresentation of curves on sags versus crests (X_1^2 = 15.72). These three relationships accounted for almost all of the overall chi-square value.

In earlier findings, the overrepresentation of downgrades relative to upgrades was suggested to have causal implications. To examine this in more detail, the data in Table 2-7 were recast to reflect the distribution of vertical alignment within horizontal alignment categories. The results are in Table 2-8.

TABLE 2-8 VERTICAL ALIGNMENT BY HORIZONTAL ALIGNMENT

	Tangent		LC		RC	
Vertical	N	%	N	%	N	%
Level	1,484	41.2	305	23.2	206	24.4
Upgrade	576	16.0	205	15.6	155	18.3
Downgrade	822	22.8	435	33.1	270	32.0
Up on Crest	206	5.7	115	8.8	52	6.2
Down on Crest	218	6.1	142	10.8	97	11.5
Up on Sag	163	4.5	60	4.6	35	4.1
Down on Sag	130	3.6	51	3.9	30	3.6
TOTAL	3,599	100.0	1,313	100.0	845	100.0

It can be seen that the overrepresentation of downgrades existed for each of the three horizontal alignment categories. Additionally, the difference in proportions of down versus upgrades varied with horizontal alignment. In agreement with the earlier tests, the statistical significance of this interaction was associated with the straight versus curved road comparison, rather than curve direction effects.

Regarding the interpretation of the interaction between vertical and horizontal alignment, some caution is required. Earlier discussions had relied on the nearly equal exposure to right and left curves and to upgrades and down; this was used as a basis for causal implications. In contrast, the assumption, for example, that horizontal curves occur with the same relative frequency on grades as they do on level roads has not been demonstrated to be valid. Thus, the results above reflect the magnitude of the single vehicle accident problem for various combinations of horizontal and vertical alignment, but over-represented combinations may be due to differential risk or differential exposure, or both.

However, it can be noted that a left curve on a downgrade in one direction represents a right curve on an upgrade in the opposite direction; thus, these two conditions presumably had essentially equal exposure. There were 435 accidents at sites having the dual disadvantage of left curves and downgrades. In the opposite direction, where neither disadvantage was present, there were only 155 accidents. On the assumption of equal exposure, the combination of the two high risk situations yielded an accident rate 2.8 times as great as the combination of the two low risk situations.

There remains the contrast between left curves on upgrades and right curves on downgrades. Here the high and low risk conditions were combined. Because there were more accidents for right curves on downgrades (270) than for left curves on upgrades (205), a dominance of vertical alignment over horizontal alignment in influencing accident generation was implied.

The interaction of vertical alignment and road condition for undivided roads was found to be significant ($X^2_{12} = 35.61$). The distribution is shown in Table 2-9.

TABLE 2-9 VERTICAL ALIGNMENT BY ROAD CONDITION

(Undivided Roads)

	Road Condition					
	Dry		Wet		Winter	
Vertical Alignment	N	%	N	%	N	%
Level	1,478	38.6	194	33.6	89	32.0
Up on Tangent	535	14.0	96	16.6	39	14.0
Down on Tangent	1,016	26.5	165	28.6	71	25.5
Up on Crest	233	6.1	32	5.5	28	10.1
Down on Crest	302	7.9	52	9.0	15	5.4
Up on Sag	151	3.9	18	3.1	17	6.1
Down on Sag	114	3.0	20	3.5	19	6.8
TOTAL	3,829	100.0	577	100.0	278	100.0

In comparison to dry roads, the major effects were proportionately fewer accidents on wet or wintry level roads, an overrepresentation of tangent grades among wet roads, and an overrepresentation of vertical curves among icy or snowy roads. In spite of the statistical significance of observed differences, the reasons for the results are not clear and may, indeed, reflect an interaction between climate and terrain irrespective of accidents.

A final point is that the overrepresentation of downgrades versus upgrades was essentially unchanged from one road condition to the next.

Summarizing the effects of vertical alignment, the major effect was the overrepresentation of downgrades relative to upgrades as accident locations. This effect, like the overrepresentation of left curves, was associated exclusively with undivided roads. Vertical alignment was found to interact with horizontal alignment in that the proportion of horizontal curves associated with any vertical alignment category was greater than the proportion of horizontal curves associated with level roads.

Vertical alignment was shown to interact with road condition in that as road conditions worsened, proportionately fewer accidents occurred on level roads. The overrepresentation of downgrades relative to upgrades was independent of road conditions.

2.3 Effect of Previous Road Alignment

For each accident location, the vertical and horizontal alignment preceding and following the location were coded. The effect of the preceding roadway alignment on the precipitation of accidents can be determined by considering the univariate distribution of distance of the accident location from the prior horizontal or vertical curve. This is based upon the assumption that if a curve preceding the accident location had no effect on the incidence of accidents, the distribution of distance of the accident location from the prior curve would be expected to be uniform. The distribution of distances to the end of the preceding horizontal curve is presented in Table 2-10.

TABLE 2-10 DISTANCE FROM PREVIOUS HORIZONTAL CURVE
(Feet)

	N	%
0-200	457	33.9
201-400	416	30.9
401-600	214	15.9
601-800	149	11.1
801-1,000	112	8.3
TOTAL	1,348	100.0

The distribution in Table 2-10 shows that as the distance from the prior horizontal curve increased, the proportion of accidents decreased. This suggests that horizontal curves are conducive to the occurrence of accidents downstream.

Of the 873 accidents which occurred within 400 feet of the previous horizontal curve, 654 (75%) occurred on a straight road segment. As the distance from the preceding horizontal curve increased, the proportion of accidents which occurred on straight roads decreased. This interaction most likely has no causal implications, but rather is likely to be a reflection of the fact that a straight road segment is most likely to follow immediately after a curve.

The univariate distribution of distances from the preceding vertical curve shown in Table 2-11 was very similar to that associated with preceding horizontal curves. The reduction of accident frequencies with increasing distances from a vertical curve indicated that recently negotiated vertical curves were causally related to the precipitation of single vehicle accidents.

TABLE 2-11 DISTANCE FROM PREVIOUS VERTICAL CURVE (Feet)

	N	%
0-200	514	32.2
201-400	348	21.8
401-600	302	18.9
601-800	239	15.0
801-1000	193	12.1
TOTAL	1,596	100.0

2.4 Pavement Edge Lines

As discussed in the methodology section, the presence of any pavement edge lines bordering the traveled direction lanes was coded. On the typical two-lane, two-way highway, only the right edge line is shown since the left edge line borders the opposing traveled direction. Table 2-12 presents the distribution of pavement edge lines for each of the two primary roadway types. Unknowns have been omitted from the table.

TABLE 2-12 PAVEMENT EDGE LINES BY ROADWAY TYPE

	Undivided		Divided & Separated	
	N	%	N	%
None	2,735	44.6	40	3.4
Right Side Only	3,304	53.9	33	2.8
Right and Left Side	88	1.4	1,087	93.7
TOTAL	6,127	100.0	1,160	100.0

For divided and separated roadways, 94 percent of the accident locations had pavement edge lines on both sides of the travel lanes. On undivided roads, 45 percent of the accident locations had no pavement edge markings.

In an attempt to determine the effectiveness of pavement edge lines, their presence was compared among the various lighting conditions. The distribution is presented in Table 2-13. Since the coding of pavement edge lines was done according to their existence, accidents which occurred on winter-covered roads, where visibility was not certain, were omitted from this sample. Roads were either dry or wet. Also, only undivided roads were included in this table.

TABLE 2-13 PAVEMENT EDGE LINES BY LIGHT CONDITION

(Undivided Roads)

	None		Right Only	
Light Condition	N	%	N	%
Day	1,288	50.8	1,608	51.5
Dawn/Dusk	89	3.5	127	4.1
Dark, Lites	39	1.5	48	1.5
Dark, No Lites	913	36.0	1,045	33.5
Dark, Lites Unknown	208	8.2	293	9.4
TOTAL	2,537	100.0	3,121	100.0

The effectiveness of pavement edge lines would be demonstrated by differences in proportions of day vs. nighttime accidents at locations with and without pavement edge lines. Specifically, if pavement edge lines were effective in reducing accident occurrence, the set of accidents which occurred on roads with edge lines should have a higher proportion of daytime accidents than the set of accidents which occurred on roads without edge lines. A two-way chi-square was performed on the data and the result was not significant ($X_4^2 = 6.08$). A direct comparison of daytime accidents versus those at night with no lights also failed to show significance ($X_1^2 = 2.19$). One possible confounding factor is the fact that no consideration was made of the condition of the pavement edge lines. That is, since photologs were the primary source

of information regarding the presence of pavement edge lines, the visibility of the lines was likely to vary depending upon the age of the photograph. In any event, given the data quality, pavement edge lines showed no effect in terms of accident occurrence for the various light conditions.

2.5 Delineators

The presence of delineators at the accident locations was coded. The distribution of reflective delineators for the two primary roadway types is presented in Table 2-14.

TABLE 2-14 DELINEATION BY ROADWAY TYPE

	Undivided		Divided & Separated		Total	
	N	%	N	%	N	%
None	4,836	81.4	153	14.2	4,989	71.0
Right Side	926	15.6	298	27.6	1,224	17.4
Right & Left Sides	14	0.2	627	58.0	641	9.1
Spot Location	165	2.8	3	0.3	168	2.4
TOTAL	5,941	100.0	1,081	100.0	7,022	100.0

As indicated, overall, delineators were present at 29 percent of the accident locations. Where present on undivided roads, delineators were present on the right side only. The difference in proportions of accident locations with and without delineators shows that delineation is primarily associated with divided roads. For this set of accidents, 86 percent of the locations were treated with delineators.

Since delineation was primarily associated with divided and separated roads, the effectiveness was studied for the set of accidents which occurred on these roads. The interaction of delineation presence and light condition was tested and found to be not statistically significant ($X_2^2 = 4.24$). That is, the proportion of day versus nighttime accidents was essentially the same for locations with and without delineators. Thus, there was no evidence of the effectiveness of reflective delineators for undivided roads.

2.6 Summary of Findings for Predeparture Factors

1. The horizontal alignment at the accident location was one of the most important factors related to the occurrence of the sampled accidents. Fifty-seven percent of the accidents occurred on straight roads, 39 percent on curves. Left curves were overrepresented relative to right curves as accident locations. This was only true for undivided roads and those of low ADT.

2. Road condition was found to interact with horizontal alignment. As road condition worsened (dry to wet to snow/ice) the difference in proportions of left versus right curves disappeared. In addition, as road conditions worsened, the overall proportion of accidents occurring on curves decreased.

3. Several driver variables were found to interact with horizontal alignment. Unfamiliar drivers were more likely than familiar drivers to depart from a curve. Drivers reported as having been drinking were more likely than nondrinkers to have departed from a horizontal curve.

4. The effects of vertical alignment were also found to be of major importance. It was found that downgrades were overrepresented as accident locations. This was true only for undivided roads.

5. The interaction of horizontal and vertical alignment indicated that the combination of curves and grades may be important for the generation of accidents. That is, for any type of grade, the proportion of accidents which occurred on curves was greater than the proportion of curves on level roads. The overrepresentation of left curves relative to right curves was found for all categories of vertical alignment. Left curves on downgrades appeared to be particularly hazardous.

6. Upgrades and downgrades were slightly overrepresented among wet roads, and vertical curves were substantially overrepresented among icy or snowy roads.

7. Horizontal and vertical curves were found to be conducive to the occurrence of accidents at downstream locations.

8. Pavement edge lines were not found to affect the proportion of accidents at night on undivided roads. Reflective delineators, found primarily on divided roads, also showed no demonstrable effect on the proportion of nighttime accidents.

3. ROAD DEPARTURE

The analytical link between the on-road phenomena and crash characteristics is the departure. Traditionally, the departure has been characterized in terms of the departure angle and speed. In the present analyses, road departure is characterized in terms of departure angle and the departure attitude. The usefulness of departure angle depends upon its predictive value in subsequent analyses pertaining to the accident outcome (e.g., severity, rollover, etc.). The departure attitude provides a more readily interpretable characterization of the departure in that regardless of the outcome of the accident, situations associated with relatively high proportions of non-tracking vehicles may be worthy of countermeasure attention. Furthermore, there exists a strong interaction between angle of departure and the departure attitude.

3.1 Departure Location

In addition to the angle of departure and departure attitude, a distinction which will be used throughout the present and following sections is the departure location. The distribution of departure locations is presented in Table 3-1.

TABLE 3-1 DEPARTURE LOCATION

	N	%
Right	4,940	62.0
Left	2,434	30.5
Median	400	5.0
T, Y Intersection, Jogged, Lanedrop	173	2.2
Unknown	25	0.3
TOTAL	7,972	100.0

As indicated, 62 percent of the accidents involved departures from the right side of the road, with 36 percent involving left side departures (including median departures). The fourth category consists primarily of vehicles driving straight through T or Y intersections. The underrepresentation of left departures presumably reflects the existence of the oncoming traffic lane on the left, which, in the absence of oncoming traffic, can be used as a buffer for correction of minor deviations from the travel lane. On the right side, no similar paved area for correction after minor lane deviations can be relied upon. This, of course, is based upon the assumption that the majority of vehicles, prior to departure, were traveling in the right lane. An empirical validation of this assumption was possible, and is presented in Table 3-2.

TABLE 3-2 DEPARTURE POINT BY TRAVEL LANE

Departure Point	Travel Lane 1 N	Travel Lane 1 %	Travel Lane 2 N	Travel Lane 2 %
Right	4,677	66.7	164	25.3
Left	2,039	29.1	261	40.3
Median	115	1.6	219	33.8
Other/Unknown	180	2.6	3	0.5
TOTAL	7,011	100.0	647	100.0

Overall, 7,011 (88 percent) of the accident vehicles were traveling in the right-most lane (Travel lane 1) prior to departure. Of these, 67 percent departed on the right side, and 31 percent on the left (including median departures). Of the 647 vehicles traveling in Lane 2, 74 percent (40 + 34) departed on the left side. Left departures, as opposed to median departures, from Lane 2 refer almost exclusively to undivided roads, a situation in which the driver was most likely attempting to pass another vehicle. Left departures onto the median refer to divided roads. In this situation, the driver may or may not have been attempting to pass another vehicle.

3.2 Departure Angle

In the study sample, departure angles were selected from one of several sources. First of all, as discussed in the methodology section, investigators were instructed to measure various lateral and longitudinal distances from the departure point. Using the appropriate trigonometric function, the departure angle was calculated from these distances. In addition, investigators photographed the point of departure from directly above the point. This was to allow measurement of departure angle from the photograph. When the lateral and longitudinal distances were relatively long, such that the reliability of the assumption of a straight path was suspect, the photographic measurements were selected as the primary source of departure angle. The following two tables (3-3 and 3-4) present the distribution of departure angles (initial departure) for undivided and divided roads, respectively. Because the departure angle differed according to the lane from which the vehicle departed, the frequencies were categorized accordingly. The distribution was also separated according to departure location. At the bottom of each column, the mean departure angles are given. In addition, cumulative proportions are presented in the tables. Departures involving unusual configurations (e.g., vehicle driving straight off the roadway), or unknown travel lane were omitted from these tables.

The most frequent event on undivided roads was a vehicle departing on the right side of the road, from the right side lane (Travel Lane 1). For this set of departures, the mean departure angle was 12.91 degrees. From the cumulative proportions, it can be seen that for this set of departures, approximately 70 percent involved departure angles of 15 degrees or less.

The second most frequent event which occurred on undivided roads was a left side departure from the right-most travel lane. For this set of departures, the mean departure angle was 19.91 degrees. As indicated by the cumulative proportions, more than half of these departures involved departure angles greater than 15 degrees.

TABLE 3-3 DEPARTURE ANGLE BY DEPARTURE POINT BY TRAVEL LANE

Undivided Roads

	Right Departures						Left Departures					
	Travel Lane 1			Travel Lane 2			Travel Lane 1			Travel Lane 2		
Angle (Degrees)	N	%	Cum. %	N	%	Cum. %	N	%	Cum. %	N	%	Cum. %
0-2.99	239	7.4	7.4	0	0	0.0	32	2.0	2.0	5	2.8	2.3
3-5.99	521	16.2	23.7	4	4.0	4.0	94	5.9	8.0	32	17.8	20.6
6-8.99	718	22.4	46.0	13	13.1	17.2	234	14.8	22.8	46	25.6	46.1
9-11.99	541	16.8	62.9	17	17.2	34.3	237	15.0	37.8	30	16.7	62.8
12-14.99	227	7.1	69.9	14	14.1	48.5	127	8.0	45.8	15	8.3	71.1
15-20.99	435	13.5	83.5	20	20.2	68.7	279	17.7	63.5	15	8.3	79.4
21-29.99	261	8.1	91.6	14	14.1	83.8	248	15.7	79.2	20	11.1	90.6
30-45.99	190	5.9	97.5	10	10.1	92.9	228	14.4	93.6	14	7.8	98.3
46-79.99	68	2.1	99.7	5	5.1	98.0	94	5.9	99.6	3	1.7	100.0
80-90.99	11	0.3	100.0	2	2.0	100.0	7	0.4	100.0	0	0.0	100.0
Total Known	3,211	100.0		99	100.0		1,580	100.0		180	100.0	
Unknown	877			25			339			64		
TOTAL	4,088			124			1,919			244		
Mean Departure Angle	12.91			20.38			19.91			13.44		

TABLE 3-4 DEPARTURE ANGLE BY DEPARTURE POINT BY TRAVEL LANE

Divided Roads

	Right Departures						Left Departures					
	Travel Lane 1			Travel Lane 2			Travel Lane 1			Travel Lane 2		
Angle (Degrees)	N	%	Cum. %	N	%	Cum. Prop.	N	%	Cum. %	N	%	Cum. %
0-2.99	12	3.8	3.8	1	4.5	4.5	3	3.0	3.0	8	6.8	6.8
3-5.99	34	10.8	14.6	0	0.0	4.5	7	7.0	10.0	13	11.0	17.8
6-8.99	54	17.2	31.5	0	0.0	4.5	10	10.0	20.0	27	22.9	40.7
9-11.99	43	13.7	45.5	2	9.1	13.6	19	19.0	39.0	28	23.7	64.4
12-14.99	29	9.2	54.8	3	13.6	27.3	14	14.0	53.0	2	1.7	66.1
15-20.99	63	20.1	74.8	4	18.2	45.5	13	13.0	66.0	19	16.1	82.2
21-29.99	43	13.7	88.5	4	18.2	63.6	14	14.0	80.0	18	15.3	97.5
30-45.99	27	8.6	97.1	5	22.7	86.4	16	16.0	96.0	2	1.7	99.2
46-79.99	8	2.5	99.7	2	9.1	95.5	3	3.0	99.0	1	0.8	100.0
80-90.99	1	0.3	100.0	1	4.5	100.0	1	1.0	100.0	0	0.0	100.0
Total Known	314	100.0		22	100.0		100	100.0		118	100.0	
Unknown	244			16			101			107		
TOTAL	558			38			201			225		
Mean Departure Angle	16.02			28.00			18.82			12.05		

The remaining two sets of departures from undivided roads were relatively infrequent events. This is due to the fact that the majority of undivided roads were two-lane roads. The sets of departures from the second travel lane implies, therefore, that the vehicle was either passing or driving in the oncoming traffic lane for some other reason.

Comparison of the four mean departure angles reveals the effect of the traversal of a lane, prior to road departure, on the departure angle. For example, right departures from travel lane two and left departure angles from travel lane one both involve traversal of a lane prior to departure. These two sets of departures have similar distributions of departure angles and consequently similar mean departure angles. Similarly, right departures from travel lane one and left departures from travel lane two both involve the vehicle departing directly off the roadway, without crossing an additional lane. These two distributions are similar, as are the mean departure angles. Overall, the traversal of an additional lane prior to departure was conducive to larger departure angles. Note that this result applied to both divided and undivided roads.

In another respect, the two road types were dissimilar. Considering only departures from lane number 1, the mean departure angles for left departures were similar for divided and undivided roads. However, right side departure angles were larger for divided versus undivided roads. This may reflect, in part, the wider shoulders generally associated with divided roads, which could allow for corrections following minor lane departures to the right in the same way that the oncoming lane does for left departures. Small cell frequencies precluded similar consideration of departures from lane number 2.

3.3 Departure Attitude

In addition to departure angle, the nature of the departure was characterized according to the attitude of the vehicle immediately prior to departure. For each departure, where physical evidence was available, it was recorded whether or not the rear wheels were in line with the front wheels. In the former case, the vehicle was said to have been "tracking". In the latter case, where the two sets of wheels were not in line, the implication is that the vehicle was either rotating or skidding sideways. Although this is not a totally direct indication of loss of control, it is generally considered to be the case that a non-tracking vehicle is out of the driver's control. Table 3-5 presents the frequencies of tracking and non-tracking vehicles categorized according to the point of departure. Departure attitude is that associated with the initial departure.

TABLE 3-5 DEPARTURE ATTITUDE BY DEPARTURE POINT

	Right		Left		Other/Unknown		Total	
	N	%	N	%	N	%	N	%
Tracking	3,240	76.1	1,315	56.8	119	68.8	4,674	69.3
Not Tracking	1,018	23.9	999	43.2	54	31.2	2,071	30.7
Total Known	4,258	100.0	2,314	100.0	173	100.0	6,745	100.0
Unknown	682		520		25		1,227	
TOTAL	4,940		2,834		198		7,972	

†

Of these 6,745 accidents, 69 percent involved vehicles tracking immediately prior to departure. For departures on the right side of the road, approximately one-fourth (24%) of the vehicles were not tracking. Of the departures from the left side of the road, 43 percent of the vehicles were not tracking. In other words, left side departures involved a significantly (X_1^2 = 261.56) higher proportion of loss of control. It should be noted that because both undivided and divided roads are included in the frequencies

the left departures involve a certain number of vehicles traveling in the passing lane and departing onto the median. The characteristics of this type of departure are similar to those associated with right side departures, in that departure does not involve traversal of a lane prior to leaving the roadway.

In an attempt to determine if the departure characteristics of vehicles traveling in lane 2 were different from those traveling in lane 1, a test was performed on the interaction of travel lane and departure attitude. The results (X_1^2 = 1.44) indicated no significant interaction.

Mean departure angles are presented for right and left departures as a function of departure attitude in Table 3-6.

TABLE 3-6 MEAN DEPARTURE ANGLE - DEPARTURE ATTITUDE BY DEPARTURE POINT

	Right Side		Left Side		Total	
	Angle (Deg.)	Freq.	Angle (Deg.)	Freq.	Angle (Deg.)	Freq.
Tracking	11.17	2,534	15.46	1,056	14.29	3,697
Not Tracking	20.36	726	22.84	720	22.80	1,485
OVERALL	13.52	3,710	18.57	2,109	16.82	5,970*

Overall, as indicated, left side departures on the average involved larger departure angles than right side departures. As discussed above, this difference may, in part, reflect the existence of the opposing lane on the left,

* The frequency information is presented only to provide an indication of the reliability of the calculated mean. As such, because unknowns are omitted, frequencies do not necessarily add across rows or columns.

which, in the absence of oncoming traffic, can act as a buffer, allowing for corrections following minor lane deviations. That is, minor deviation to the right will result in departing the road with a small departure angle. In contrast, a similar deviation to the left is more likely to be correctable before departure. Following this rationale, the difference in mean departure angles for right and left departures derives, in part, from the composition of the sample; that is, more small departures are sampled on the right than on the left.

Another possible explanation is that the opposing traffic lane provides more lateral distance allowing for larger departure angles. Specifically, a constant steer angle to the left will result in a greater departure angle than would the same steering input to the right. This argument pertains primarily to tracking vehicles. As indicated in the table, the mean departure angle associated with tracking vehicles is larger for left side departures than for right side departures.

A final proposed explanation pertains to the differences in proportions of tracking and non-tracking vehicles between left and right departures, as discussed in conjunction with the previous table. Since left departures involved a higher proportion of non-tracking vehicles than did right departures, and since the mean departure angle associated with non-tracking vehicles was greater than that associated with tracking vehicles, it could have been expected that the difference in mean departure angle between right and left departures would be related to the higher likelihood of loss of control for left departures.

Consideration of the individual cells of the table reveals an interaction of departure location and departure attitude in terms of departure angle. The smallest mean departure angle was associated with right departures where the vehicle departed with both sets of wheels in line, or tracking. The largest mean departure angle was that associated with left departures where

the vehicle was not tracking. Also of interest is that the mean departure angle for non-tracking right departures was greater than the mean departure angle for tracking left departures. That is, on the average, all non-tracking angles were greater than all tracking departure angles.

3.4 Horizontal Alignment

In a previous section, it was determined that differences in proportions of accident occurrence associated with the various elements of horizontal alignment suggested causal implications. Specifically, the over-representation of left curves as accident locations indicated a problem area. In the current section, the departure characteristics associated with the elements of horizontal alignment are discussed.

The frequencies of combinations of departure location and horizontal alignment are presented schematically in Figure 3-1.

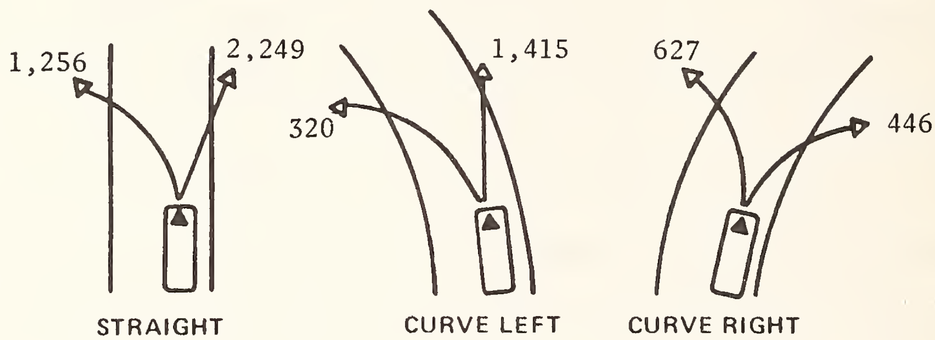

FIGURE 3-1 DEPARTURE LOCATION BY HORIZONTAL ALIGNMENT FREQUENCIES
(Undivided Roads)

The pattern of frequencies reflected in Figure 3-1 is identical to that found by Perchonok*. As discussed therein, the ordering of frequencies was interpreted as supporting two basic hypotheses: (1) it is easier to hit something (the road edge) close than far away; and (2) it is easier to go straight than to turn. Furthermore, according to Perchonok, the two phenomena operate jointly. For example, departing straight ahead on a left curve involves both hitting something close and going straight rather than turning; this was the most frequent departure type on curves. This is in contrast, for example, to accidents which involved departing straight ahead on a right curve. These accidents represented the two forces in conflict, and occurred much less frequently.

It is clear that departures on horizontal curves were most likely to have involved the driver continuing on a straight path rather than turning too sharply. Thus, departures occurred more frequently on the outside of curves, rather than the inside.

In order to examine the effect of degree of curvature on departure location, Table 3-7 was generated. It shows the departure point as a function of curvature; left and right curves were tabulated separately.

The results show that on left curves the proportion of right side departures increased with curvature. For right curves, the proportion of left side departures increased with curvature. Or, more concisely, irrespective of the direction of the curve, the proportion of outside departures increased with curvature. Simply, the previously mentioned tendency for vehicles to turn too little rather than too much became increasingly obvious on sharper curves.

It can also be seen that the effect was greater on right curves than on left curves. This is shown explicitly at the bottom of the table.

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* Perchonok, K., "Accident Cause Analysis", Calspan Report No. ZN-5010-V-3, 1972.

TABLE 3-7 DEPARTURE POINT AS A FUNCTION OF CURVATURE FOR LEFT AND RIGHT CURVES

(Undivided Roads)

Departure Side	Departure Type	0 - 4 N	0 - 4 %	4 - 8 N	4 - 8 %	8 - 12 N	8 - 12 %	12+ N	12+ %
				- Left Curves -					
Right	Outside	488	79.3	303	84.2	155	86.1	108	88.5
Left	Inside	127	20.7	57	15.8	25	13.9	14	11.5
Total		615	100.0	360	100.0	180	100.0	122	100.0
				- Right Curves -					
Right	Inside	192	56.8	93	43.7	42	32.3	20	22.0
Left	Outside	146	43.2	120	56.3	88	67.7	71	78.0
Total		338	100.0	213	100.0	130	100.0	91	100.0
% Outside Left Minus Right Curves			36.1		27.9		18.4		10.5

Curvature (Degrees) applies to columns 0 - 4 through 12+.

For shallow curves, the proportion of outside departures on left curves exceeded the proportion on right curves by 36 percent; however, for curves greater than 12 degrees, the difference was reduced to ten percent. In part, this was due to the high rate of outside departures even for shallow left curves; since the upper limit is 100 percent, this precluded a substantial increase. None the less, regarding the proportion of outside departures, right curves grew to look more like left curves as the degree of curvature increased.

Table 3-8 presents the distribution of initial departure attitude as a function of horizontal alignment and point of initial departure. Only accidents occurring on undivided roads in which the vehicle departed from the rightmost travel lane are included.

TABLE 3-8 HORIZONTAL ALIGNMENT BY DEPARTURE POINT BY DEPARTURE ATTITUDE (Undivided Roads)

(Travel Lane = 1)

	Right Departures				Left Departures			
	Tracking		Not Tracking		Tracking		Not Tracking	
	N	%	N	%	N	%	N	%
Tan	1,530	80.9	362	19.1	505	57.5	374	42.5
LC	985	80.8	234	19.2	71	30.0	166	70.0
RC	212	60.1	141	39.9	258	58.6	182	41.4
TOTAL	2,727	78.7	737	21.3	834	53.6	722	46.4

Considering right departures, the results show straight roads and left curves were similar in that approximately 20 percent of the departures involved non-tracking vehicles. The proportion was twice as high for right departures from right curves.

Left departures associated with the various roadway alignments show a pattern similar to that for right departures in that the left departures from right curves and from straight roads involved essentially the same proportions of tracking vehicles. Left departures from left curves was the only category in the table for which the proportion of tracking vehicles was smaller than the proportion of non-tracking vehicles.

The pattern of the proportions of tracking and non-tracking vehicles suggests that for both right and left departures, departures on the inside of a curve (left departures from left curves and right departures from right curves) differ from departures from straight roads and departures from the outside of the curve. This is consistent with the idea that an inside departure requires a control input greater than that needed to negotiate the curve. This additional control input results in a higher probability of loss of vehicle control.

Departures from curves can be described as involving either of two types of driver/vehicle behavior. The first involves the driver "missing" the curve and departing the outside of the curve (i.e., left departures from right curves and right departures from left curves). This set of departures was shown to have had a high proportion of vehicles tracking at the point of departure, and could be expected to have a high proportion of departures involving no corrective response by the driver. The second type of departure involves the vehicle departing the inside of the curve. This set of departures has been described as requiring a control input greater than that required to negotiate the curve.

In addition to these described differences, left side departures have been described as differing from right side departures because of the existence of the oncoming traffic lane (for undivided roads). In order to determine empirically the nature of departures from curves, the interaction of driver maneuver and the resultant departure attitude for the first departure is presented for the four departure types in Table 3-9.

TABLE 3-9 MANEUVER BY DEPARTURE ATTITUDE AND DEPARTURE POINT
(Curves on Undivided Roads)

	Tracking				Not Tracking					
	Control Failure/ Attempted Correction		No Corrective Response		Control/ Failure Attempted Correction		No Corrective Response		Total	
Curve Direction-Dep. Point	N	%	N	%	N	%	N	%	N	%
Left Curve - right	396	40.3	366	37.3	213	21.7	7	0.7	982	100.0
Left Curve - left	42	19.0	19	8.6	158	71.5	2	0.9	221	100.0
Right Curve - right	88	30.8	66	23.1	131	45.8	1	0.3	286	100.0
Right Curve - left	140	33.3	101	24.0	176	41.8	4	1.0	421	100.0

As indicated by the variability across rows, the departure characteristics were considerably different for each of the departure types represented in the table. The data show that 38 percent of the right departures from left curves involved no corrective response. This was higher than for any other alignment/departure point combination. On the other hand, this also shows that the departures with no corrective response were in the minority. Thus, while drivers do miss curves, and while this is most apparent for right departures from left curves, even in this instance less than half the drivers were shown to have done so.

3.4.1 Percent of Curve Traversed

Departures from horizontal curves were also characterized in terms of the percent of the curve traversed prior to departure. There were only 1,397 accidents in which the required information was available. Table 3-10 gives the percentage of curve traversed in terms of curve length.

First of all, the righthand columns give the distribution of percent of curve traversed irrespective of curve length. Under the hypothesis of no effect, one would expect a uniform distribution with 20 percent of departures in each of the five intervals. The results show the distribution was not uniform (X_4^2 = 24.86). Rather, the smallest number of departures occurred in the 21 to 40 percent interval; then the proportions increased, reaching a maximum for the last 20 percent of the curve.

It is important to recognize that the percent of curve traversed variable was based on the point at which the vehicle departed the road, and not some prior point at which the vehicle first got into trouble. Thus, for example, a vehicle which traversed 30 percent of the curve might well have done so in response to a problem in the first twenty percent, or even a problem which arose before entering the curve.

TABLE 3-10 PERCENTAGE OF CURVE TRAVERSED BY HORIZONTAL CURVE LENGTH

Percent Curve Traversed	Horizontal Curve Length												Total	
	1-200		201-400		401-600		601-1000		1001-1500		> 1500			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
0-20	36	16.8	47	16.6	39	20.3	64	25.1	45	25.6	58	20.9	289	20.7
21-40	22	10.3	35	12.4	40	20.8	40	15.7	36	20.5	55	19.9	228	16.3
41-60	53	24.8	49	17.3	43	22.4	55	21.6	26	14.8	54	19.3	280	20.0
61-80	27	12.6	69	24.4	30	15.6	53	20.8	27	15.3	53	19.1	259	18.5
81-100	76	35.5	83	29.3	40	20.8	43	16.9	42	23.9	57	20.6	341	24.4
TOTAL	214	100.0	283	100.0	192	100.0	255	100.0	176	100.0	277	100.0	1,397	100.0

Thus, to the extent that curves present a problem to drivers, one could expect an underrepresentation of departures in the first 20 percent of the curve since the curve effects would be observed farther downstream. That there was, in fact, no underrepresentation in the first 20 percent, suggests there may have been problems prior to entering the curve. One reasonable example is the failure, when approaching the curve, to be cognizant of its existence; this would have the effect of raising the proportion of departures in the first interval above that which might otherwise be expected.

Initially, the reason for the overrepresentation of departures in the last 20 percent of the curve was not clear. It did not seem likely that this implied a transition problem, in that this could be expected to show up as departures mostly beyond the curve. Indeed, recall the earlier results showing an overrepresentation of accidents just after horizontal curves. These earlier findings may be suggestive of a transition problem, but this cannot explain the departures at the end of the curve.

The main body of the table shows that the primary contribution to the overrepresentation of departures in the last 20 percent of the curve was associated with curves less than 400 feet long. If these data were excluded, the proportion of departure in the last interval would have been 20.2 percent, almost exactly what would have been expected by chance alone.

With the view that departures reflect problems upstream, the high incidence of last interval departures for curves under 400 feet could well be indicative of problems occurring near the beginning of the curve.

In general, then, while departures were overrepresented in the last 20 percent of curves, further considerations appear to imply that the major causal problems resided at the beginning of the curve.

Summarizing the departure characteristics discussed so far, it was found that right side departures occurred more frequently than left side departures. It was speculated that the existence of the oncoming traffic lane, in the absence of oncoming traffic, acts as a buffer allowing space for drivers to regain control following minor lane deviations to the left. Since a similar buffer is not available on the right side, the accident sample would be expected to contain more right than left side departures. Consistent with this is the finding that left side departures involved larger departure angles than right side departures.

Overall, approximately 70 percent of the departing vehicles were tracking at the point of initial departure. Right side departures had a slightly higher proportion of tracking vehicles than did left side departures.

Departure attitude was found to have a strong relationship with departure angle; that is, non-tracking vehicles (i.e., vehicles out of the driver's control) involved larger departure angles for both right and left departures. The smaller departure angles associated with right side departures derives in part from the smaller proportion of non-tracking vehicles associated with right side departures. For left side lane deviations, the oncoming traffic lane, while allowing an opportunity for the driver to return to the travel lane, also allows for attempted corrections which result in a higher probability of loss of vehicle control.

Right departures from left curves on undivided roads occurred almost three times as often as any other departure configuration associated with horizontal curves. Analyses using departure attitude and the predeparture maneuver indicated that the departure characteristics were different for the different combinations of curve direction and departure point.

It was also shown that a disproportionate number of vehicles departed at the end of horizontal curves. This was due to departures on short curves which, in turn, suggested the source of the problem resided at the beginning of the curve.

3.5 Vertical Alignment

Table 3-11 presents the frequencies and proportions of tracking and non-tracking vehicles for the various categories of vertical alignment.

TABLE 3-11 DEPARTURE ATTITUDE BY VERTICAL ALIGNMENT

Gradient Description	Tracking		Not Tracking		Total	
	N	%	N	%	N	%
Level	1,236	72.9	460	27.1	1,696	100.0
Upgrade	559	70.1	238	29.9	797	100.0
Downgrade	893	67.6	428	32.4	1,321	100.0
Up Crest	216	66.3	110	33.7	326	100.0
Down Crest	266	66.0	137	34.0	403	100.0
Up Sag	144	67.3	70	32.7	214	100.0
Down Sag	123	69.5	54	30.5	177	100.0
TOTAL	3,437	69.7	1,497	30.3	4,934	100.0

Although the overall chi-square indicates a significant (X_6^2 = 15.95) interaction between the two classifications, the majority of the effect was due to the difference in proportions of tracking and non-tracking vehicles between level roads and the other vertical alignment categories (X_1^2 = 12.66). As indicated by the proportions, departures from level roads involved a higher proportion of tracking vehicles than were associated with the other categories of vertical alignment.

Previous discussion showed that for vertical alignment, the over-representation of downgrades relative to upgrades had causal implications. In contrast, Table 3-11 fails to show any important upgrade/downgrade effects on departure attitude. In general, differences in proportion of tracking vehicles as a function of vertical alignment categories were smaller than differences associated with horizontal alignment categories.

3.6 Road Condition

In addition to the roadway alignment, the condition of the road was found to effect the proportion of vehicles tracking at the point of departure. The distribution of road condition by departure attitude is presented in Table 3-12.

TABLE 3-12 DEPARTURE ATTITUDE BY ROAD CONDITION

(First Departure)

	Dry		Wet		Winter		Total	
	N	%	N	%	N	%	N	%
Tracking	4,120	75.3	421	59.8	93	18.4	4,634	69.4
Not Tracking	1,353	24.7	283	40.2	412	81.6	2,048	30.6
TOTAL	5,473	100.0	704	100.0	505	100.0	6,682	100.0

As indicated, as the road condition changes from dry to wet to winter conditions, the proportion of vehicles rotating or skidding (i.e., not tracking) prior to departure increased. For accidents which occurred on winter-covered roads, 82 percent were not tracking prior to departure.

In a separate analysis, road condition was also found to be significantly interactive (X_2^2 = 13.91) with point of departure. As road conditions deteriorated, the proportion of left departures increased. On dry pavements, 34 percent of the departures were from the left side; the corresponding figures for wet and winter covered roads were 39 and 41 percent, respectively.

3.7 Departure Configuration

The nature of departures was further characterized by considering the resulting configuration. The distribution of configurations is presented in Table 3-13.

TABLE 3-13 DEPARTURE CONFIGURATIONS

	N	%
Single Departure	5,888	73.9
Departure & Return	314	3.9
Double Departure - one side	340	4.3
Multiple Departure - one side	17	0.2
Double Departure - two sides	1,271	15.9
Multiple Departure - two sides	74	0.9
Cross Median	43	0.5
Prior Departure - Cross Median	18	0.2
Other, Unknown	7	0.1
TOTAL	7,972	100.0

As indicated, the majority of the sampled accidents involved a single departure. When more than one departure was involved, the most frequent configuration was a double departure, with the vehicle departing once from each side of the road. Undoubtedly, the proportion of "departure and return"* accidents was underrepresented relative to the number of actual occurrences. This is due to the fact that a certain proportion of vehicles which departed from and subsequently returned to the roadway continued on their trip, without having sustained damage sufficient to disable the vehicle. Incidents such as these had no way of getting into our sample of accidents.

Table 3-14 presents the proportion of tracking and non-tracking vehicles associated with the four most frequent departure configurations. Frequencies refer to the initial departure. As is apparent, mulitple departures most often involve vehicles tracking at the point of initial departure.

TABLE 3-14 DEPARTURE ATTITUDE BY DEPARTURE CONFIGURATION

	Tracking		Not Tracking		Total	
Configuration	N	%	N	%	N	%
Single Departure	3,064	62.2	1,861	37.8	4,925	100.0
Departure and Return	172	67.5	83	32.5	255	100.0
Double Departure 1 Side	281	94.9	15	5.1	296	100.0
Double Departure 2 Sides	1,046	91.8	94	8.2	1,140	100.0

* Departure and return was defined as the vehicle returning to the roadway as part of a single departure accident.

In a previous discussion, it was noted that 69 percent of the departing vehicles were tracking at the point of initial road departure. In contrast, for the final departure, seven percent of the vehicles were tracking and 93 percent were not tracking. In other words, a vehicle which was not tracking at the point of initial departure was not likely to return to the roadway and become involved in an additional event.

Table 3-15 presents mean initial departure angles for the four most frequently occurring configurations.

TABLE 3-15 MEAN DEPARTURE ANGLE (DEPARTURE CONFIGURATION BY DEPARTURE ATTITUDE)

	Tracking		Not Tracking	
Configuration	Frequency	Mean Angle (Deg.)	Frequency	Mean Angle (Deg.)
Single Departure	2,506	14.77	1,335	22.36
Departure and Return	140	9.75	67	18.15
Double Departure 1 Side	166	7.13	5	16.14
Double Departure 2 Sides	734	7.43	49	12.04

Mean departure angles were categorized according to the departure attitude associated with the initial departure. As is evident, the mean departure angles in every category of departure configuration were larger for non-tracking vehicles. For both tracking and non-tracking vehicles, the occurrence of multiple events (i.e., more than a single departure) was associated with smaller mean departure angles than those associated with single departures.

Thus, multiple departure accidents tended to result from initial departures in which the vehicle was tracking and the angle was small. This reflects a typical accident type in which the initial departure was a shallow one with no impacts, only to be followed by subsequent damage-inducing departures.

The four primary departure configurations were also compared with regard to point of initial departure. The proportions of right and left side departures for the four configurations are presented in Table 3-16 below.

TABLE 3-16 CONFIGURATION BY DEPARTURE POINT

Configuration	Right N	Right %	Left N	Left %
Single Departure	3,381	69.7	2,070	86.0
Departure and Return	204	4.2	96	4.0
Double Departure 1 Side	254	5.2	60	2.5
Double Departure 2 Sides	1,012	20.9	181	7.5
TOTAL	4,851	100.0	2,407	100.0

According to the proportions, a left side departure was more likely than a right side departure to result in a single departure. Whereas 14 percent of the vehicles which initially departed on the left side of the road were involved in more than a single departure, the corresponding figure for right side departures which resulted in more than a single departure was 30 percent. That is, a vehicle departing on the right side was approximately twice as likely as a vehicle departing on the left to have returned to the roadway. The higher proportion of multiple departures for initial departures to the right was consistent with the higher proportion of tracking vehicles and small departure angles for right side departures.

3.8 Summary of Findings for Departure Characteristics

1. Overall, right side departures were more prevalent than left side departures. Left side departures involved larger proportions of non-tracking vehicles and larger departure angles than did right side departures. The overall mean departure angles for right and left departures were 13.52 and 18.57, respectively.

2. For describing departure characteristics, the departure attitude (i.e., proportion of tracking vehicles) was found to be more useful than departure angle. Overall, approximately 70 percent of the accident vehicles were tracking at the point of departure. The overall mean departure angle associated with tracking vehicles was 14.29 degrees. That associated with non-tracking vehicles was 22.80 degrees.

3. For curves on undivided roads, right departures from left curves occurred more than twice as often as the next largest set of departures. The proportion of departures to the outside of curves increased with degree of curvature.

4. For the four combinations of curve direction and side of departure, the departure characteristics were very different in terms of departure attitude and predeparture maneuver, and departure angles.

5. Outside departures from curves and departures from straight roads had similar departure attitudes, given the departure side. Inside departures had more nontracking vehicles than did either of the above. Outside departures reflected no corrective driver response more often than did inside departures.

6. For left side departures, the existence of the opposing traffic lane on undivided roads provided an opportunity for corrections following minor lane deviations. It also allowed space for attempted corrections resulting in a higher probability of loss of control.

7. With regard to point of departure along a horizontal curve, departures at the very end of curves were overrepresented. This was true only for shorter curves on undivided roads, thereby suggesting problems originating at the beginning of the curve.

8. On grades of any type, the proportion of non-tracking vehicles was larger than on level roads.

9. As road conditions worsened, the proportion of non-tracking departures increased.

10. Seventy-four percent of the sampled accidents involved only a single departure. When more than one departure was involved, the most frequent configuration was a double departure, with the vehicle departing once from each side of the road.

11. Vehicles departing on the right with smaller initial departure angles and a tracking attitude were most likely to be involved in multiple departure accidents.

4. OFF-ROAD FACTORS

While the previous sections were primarily concerned with road characteristics, on-road events, and departure characteristics, Section 4 is addressed to departure characteristics, off-road events, and distances traveled. The sections following this will treat the nature of impacts and accident severity.

4.1 Background Information

4.1.1 Definitions

- Each accident has one or more <u>phases</u>. For most purposes, a phase can be viewed as synomymous with a road departure. More specifically, however, a phase is initiated when any part of the vehicle leaves the road (the traveled portion of the road) or strikes an object immediately adjacent to the road. In a multiple departure accident, a phase is concluded with the next departure. Thus, an accident in which the vehicle departs to the right, returns to the road, and departs to the left, is a two phase accident. The first phase starts at the point of the first departure and includes all events occurring while the vehicle is on the right roadside (including the right shoulder) plus any events occurring while the vehicle is crossing the road. The first phase ends and the second phase starts when the vehicle departs the left-hand side of the road. Had the vehicle departed to the right, returned to the road, and departed to the right once again, this, too, would have been a two phase accident.

Table 4-1 gives the distribution of number of phases per accident. The table shows that over three-fourths of the accidents had only one phase. Only one percent of the accidents had more than two phases.

TABLE 4-1 NUMBER OF PHASES

Number of Phases	N	%	C %
1	6242	78.3	78.3
2	1637	20.5	98.8
3	86	1.1	99.9
4	4	0.1	100.0
5	3	0.0	100.0
Total	7972	100.0	

- Each phase has at least one event. An event is said to have occurred whenever there was (1) a rollover, (2) a nonrollover impact, or (3) a phase was completed in which neither (1) nor (2) occurred. In the example above, if the vehicle departed to the right, struck nothing and experienced no rollovers, and then departed the left side, struck a tree and stopped, two events would have occurred. The first, occurring in phase one, would be a nonimpact departure. The second, occurring in the second phase, would be striking the tree.

Table 4-2 gives the joint distribution of number of events and number of phases for the accident sample. The marginal distribution of events is shown to the right. By summing 1 X 3,828 and 2 X 2,986, etc. , it can be shown that the total number of events was 13,484.

TABLE 4-2 NUMBER OF EVENTS AND NUMBER OF PHASES

Number of Events	Number of Phases: 1		2		3		4		5		Total	
	N	%	N	%	N	%	N	%	N	%	N	%
1	3,828	48.0	0		0		0		0		3,828	48.0
2	1,898	23.8	1,088	13.6	0		0		0		2,986	37.5
3	425	5.3	471	5.9	60	0.8	0		0		956	12.0
4	91	1.1	77	1.0	24	0.3	4	0.1	0		196	2.5
5	0		0		2		0		2	0.0	4	0.1
6	0		1	0.0	0		0		1	0.0	2	0.0
Total	6,242	78.3	1,637	20.5	86	1.1	4	0.1	3	0.0	7,972	100.00

Considering events and phases together, the table shows the simplest combination, one event in a single phase, accounted for almost one-half of the accidents. This represents an accident in which the vehicle departed the road and either rolled over or struck an object and came to final rest. Also included could be a limited number of accidents in which the vehicle simply left the road, experienced no impacts, and stopped; in those cases, the vehicle might not have returned to the road because the driver was shaken up or because the terrain precluded it.

The second most frequent event/phase combination was two events in a single phase accident. These accidents involved a single departure with two impacts; they accounted for almost one-fourth of all accidents.

Fourteen percent of the accidents involved two phases and two events. Typically, these were accidents in which the vehicle departed one side of the road, experienced no impacts, returned to the road and departed once again, and experienced one impact in the second phase.

These three event/phase combinations accounted for 85 percent of all the accidents in the sample. Another eleven percent of the accidents involved either three events in a single phase, or three events and two phases.

- As noted above, three <u>event types</u> were defined. An event could be a rollover, a nonrollover impact, or a completed phase in which neither a rollover or nonroll impact was experienced. For convenience, rollovers and nonroll impacts were generally referred to as impacts.

  Given this, any event was either an impact or nonimpact. Impacts were either rollovers or nonrollovers. As will be shown shortly, some limited number of events involved an impact with an object during a rollover. These events were grouped with other rollovers.

Table 4-3 gives the distribution of event types for all events, and then for first events alone. The table shows that of all events, approximately one-half were nonrollover impacts and one-third were rollovers. When considering only first events, there were relatively fewer rollovers, somewhat more nonroll impacts, and more nonimpact events. One point shown here, then, is that the likelihood of a nonimpact event (i.e., a departure with no impacts) was higher in the first phase than in later ones.

TABLE 4-3 EVENT TYPE

	All Events		First Events	
Type	N	%	N	%
Rollover	4.246	31.5	1,528	19.2
Nonrollover	7,517	55.7	5,031	63.1
No Impact	1,714	12.7	1,412	17.7
Unknown	7	0.1	1	0.0
TOTAL	13,484	100.0	7,972	100.0

Table 4-4 provides a different view of rollover frequencies. It gives the distribution of known rollovers per accident. A rollover may be 90 degrees, 180 degrees, etc.; in any case, it is a single discrete rollover. This table gives the number of such discrete rollovers per accident.

TABLE 4-4 ROLLOVER EVENTS

Number of Rollover Events	Frequency	Percent
None	4,157	52.1
1	3,416	42.8
2	368	4.6
3	30	0.4
4	1	0.0
TOTAL	7,972	100.0

In 52 percent of the accidents, there were no known rollovers. Conversely, in almost one-half of the accidents (48%), there was at least one rollover. Forty-three percent had exactly one rollover and five percent had two or more.

Reviewing the terms hereby introduced, a phase was initiated whenever the vehicle left the road; it continued until a later departure occurred. An event was said to occur whenever there was an impact or a completed phase with no impacts. An impact was either a rollover or a nonrollover impact.

4.2 Event Type

In the following, event types are explored in more detail. In particular, factors affecting event type are examined. The major importance of event type rests largely on two factors. The first is the role of nonimpact events. Because the data sample contained no nonaccident data, it was impossible to determine the overall effect of nonimpact events. However, since a departing vehicle cannot avoid an accident unless it gets away in the first departure, the analysis of nonimpacts pertains to the opportunity for accident avoidance. That is, as the number of nonimpact first departures increases, the likelihood of any impact at all decreases.

The second factor pertains to the importance of rollovers in causing injury. This will be discussed later in detail, but the pertinent fact is that on the average, rollovers were more conducive to occupant injury than were nonroll impacts.

4.2.1 Phase Number

Table 4-5 gives event type as a function of phase number. It shows that while 29 percent of the events in phase one were rollovers, fully 42 percent of the phase two events were rollovers. In phase three, the proportion of rollovers dropped to a level near that for phase one.

TABLE 4-5 EVENT TYPE BY PHASE NUMBER

(All Events)

	Event Type							
	Rollover		Nonrollover		No Impact		Total	
Phase Number	N	%	N	%	N	%	N	%
1	3,268	29.4	6,397	57.5	1,452	13.1	11,117	100.0
2	945	42.1	1,075	47.8	227	10.1	2,247	100.0
3	31	29.5	41	39.0	33	31.4	105	100.0
4	1	16.7	4	66.7	1	16.7	6	100.0
5	1	50.0	0	0.0	1	50.0	2	100.0

Initially, an explanation for this apparent anomoly could not be found, then a rather simple explanation was explored. It seemed reasonable that a rollover was more likely than any other event type to end an accident sequence. In order to examine this and its effects on phase number, Table 4-6 was developed. It gives event type as a function of phase number within the number of the phases in the accident.

First of all, Table 4-6 supports the basic premise that rollovers tend to end the accident sequence. This is shown by the fact that the proportion of rollovers increased with each successive phase. For example, in two phase accidents, six percent of the phase one events were rollovers, while 44 percent of the phase two (the last phase) events were rollovers. In three phase accidents, none of the events were rollovers in phase one, 14 percent were rollovers in phase two, and 32 percent were rollovers in the last phase.

The proportion of rollovers for all phase two events is given by a weighted average of the proportions of rollovers in phase two of two phase accidents, three phase accidents, etc. Because there were so many more accidents with two phases than with three or more phases, the overall proportion

TABLE 4-6 EVENT TYPE BY PHASE NUMBER AND NUMBER OF PHASES

Number of Phases	Phase Number	Event Type: Rollover N	Rollover %	Nonrollover N	Nonrollover %	No Impact N	No Impact %	Total N	Total %
1	1	3,167	34.2	5,999	64.8	96	1.0	9,262	100.0
2	1	101	5.7	378	21.5	1,282	72.8	1,761	100.0
	2	931	43.5	1,027	48.0	180	8.4	2,138	100.0
3	1	0	0.0	18	20.7	69	79.3	87	100.0
	2	14	13.9	43	42.6	44	43.6	101	100.0
	3	31	31.6	36	36.7	31	31.6	98	100.0
4	1	0	0.0	2	50.0	2	50.0	4	100.0
	2	0	0.0	2	50.0	2	50.0	4	100.0
	3	0	0.0	3	75.0	1	25.0	4	100.0
	4	1	25.0	3	75.0	0	0.0	4	100.0
5	1	0	0.0	0	0.0	3	100.0	3	100.0
	2	0	0.0	3	75.0	1	25.0	4	100.0
	3	0	0.0	2	66.7	1	33.0	3	100.0
	4	0	0.0	1	50.0	1	50.0	2	100.0
	5	1	50.0	0	0.0	1	50.0	2	100.0

is very close to that for accidents involving two phases. Thus, the higher proportion of rollovers in phase two is completely explainable by (1) the high probability of rolling over in the last phase (i.e., rollovers tend to end the accident sequence), and (2) the predominance of two phase accidents among multiple departure accidents.

Table 4-5 also shows that the proportion of events involving no impact was lowest in phase two. The explanation is quite similar to that for rollovers. The difference is that in multiple departure accidents, non-impact events were most likely in the first phase; this is shown clearly in Table 4-6. Thus, the relatively high frequency of two phase accidents and the very low proportion of events which were nonimpact events in the second phase of two phase accidents account for the overall reduction of nonimpact events in the second phase of the accidents in general.

4.2.2 Departure Angle

Two primary descriptors of road departure activity are departure angle and departure attitude. Because departure characteristics were determined for the first and last phases, only these phases were available for analysis. In order to maximize homogeneity, analytical emphasis was placed on the first phase. Similarly, because the most direct effect of the nature of the departure was likely to be reflected in the first event after departure, the analysis focused primarily on the first event. Table 4-7 gives event type as a function of departure angle. Only the first event (in the first departure) is included.

The results show that the proportion of rollovers increased fairly rapidly for departure angles less than eleven degrees. The proportion then continued to rise more slowly, reaching a maximum of 23 percent in the 30 to 45 degree range. Thereafter, the likelihood of a rollover decreased; this is particularly notable in the 80 to 90 degree range. These very high departure angles are typical of accidents at T intersections where the vehicle, traveling along the stem of the T, continued straight off the intersecting road. Therefore, the primary focus of attention in this discussion is restricted to angles of 45 degrees or less.

TABLE 4-7 EVENT TYPE BY DEPARTURE ANGLE (First Event)

Departure Angle (Degrees)	Event Type: Rollover N	Rollover %	Nonrollover N	Nonrollover %	No Impact N	No Impact %	Total N	Total %
0-2	27	8.7	130	41.7	155	49.7	312	100.0
3-5	77	10.6	403	55.3	249	34.2	729	100.0
6-8	128	11.3	743	65.5	263	23.2	1,134	100.0
9-11	180	18.7	684	70.9	101	10.5	965	100.0
12-14	86	19.3	319	71.5	41	9.2	446	100.0
15-20	182	20.8	643	73.4	51	5.8	876	100.0
21-29	136	21.0	488	75.4	23	3.6	647	100.0
30-45	120	23.1	382	73.6	17	3.3	519	100.0
46-79	43	19.5	174	78.7	4	1.8	221	100.0
80-90	6	5.0	114	95.0	0	0.0	120	100.0

It is important to see that the proportion of nonrollover impacts also increased with departure angle. Nonrollover impacts increased rapidly up to the vicinity of eleven degrees, and then rose more slowly up to the 46 to 79 degree range; thereafter, the proportion increased sharply.

The primary reason for these results can be understood by looking at the "no impact" columns. Here it can be seen that there was a definite decrease in nonimpact departures with increasing departure angle. Simply, the smaller the departure angle, the greater the opportunity for the vehicle to return to the road without incurring any sort of impact. For example, of vehicles whose departure angle was in the zero to two degree range, one-half returned to the road without impact. On the other hand, in the highest range, no vehicles returned to the road without impact.

In order to obtain a clearer picture of the effect of departure angle on rollover versus nonrollover impacts, the data were retabulated to provide information on the proportion of rollovers among all impacts after removing the nonimpact events. The results are in Table 4-8.

TABLE 4-8 ROLLOVERS AS A FUNCTION OF DEPARTURE ANGLE

Departure Angle (Degrees)	Impact Type: Rollover N	Rollover %	Nonrollover N	Nonrollover %	Total N	Total %
0-2	27	17.2	130	82.8	157	100.0
3-5	77	16.0	403	84.0	480	100.0
6-8	128	14.7	743	85.3	871	100.0
9-11	180	20.8	684	79.2	864	100.0
12-14	86	21.2	319	78.8	405	100.0
15-20	182	22.1	643	77.9	825	100.0
21-29	136	21.8	488	78.2	624	100.0
30-45	120	23.9	382	76.1	502	100.0
46-79	43	19.8	174	80.2	217	100.0
80-90	4	5.0	114	95.0	120	100.0

As before, the proportion of rollovers increased to a maximum in the 30 to 45 degree range, and then dropped to a minimum in the 80 to 90 degree range. There are, however, some differences from the previous table. First, the increasing trend, below 45 degrees, was disturbed by an initial decrease reaching a local minimum of fifteen percent in the six to eight degree range. Second, whereas the percentage of rollovers varied from nine to 23 in the previous table (ignoring very high departure angles), Table 4-8 shows a somewhat restricted range of 15 to 24 percent. Thus, when the effects of nonimpact departures were removed, the relationship between departure angle and rollover was not as strong nor as well defined.

Because the relationship between rollovers and departure angle (excluding large angles) was not an obvious one, a chi-square test was performed for angles below 46 degrees. The result was statistically significant ($X_7^2 = 29.88$), and was almost wholly accounted for by the difference between departure angles in the zero to eight degree range versus those in the nine to 45 degree range ($X_1^2 = 27.15$).

At this point then, the results show that for the first event, the primary influence of an increasing departure angle was a decrease in nonimpact events and a complementary increase in rollovers and nonrollover impacts. For very large angles, the proportion of nonrollover impacts continued to increase, while that for rollovers decreased. When the effect of departure angle on nonimpact events was removed, the high incidence of nonrollover impacts for large angles remained. However, for angles below 46 degrees, the increase in rollovers and the corresponding decrease in nonrollover impacts, which occurred near nine degrees, was statistically significant but of limited magnitude.

4.2.3 Departure Attitude

The next variable to be considered in the study of factors influencing event type was departure attitude. This variable reflects whether the vehicle was tracking immediately before departure; basically, it shows whether the vehicle was moving ahead or had a sideward skidding component at departure. Table 4-9 gives the proportion of each event type as a function of departure attitude for the first event.

TABLE 4-9 EVENT TYPE FOR DEPARTURE ATTITUDE (First Event)

	Event Type								
	Rollover		Nonrollover		No Impact		Total		
Attitude	N	%	N	%	N	%	N	%	% Rollover for Impacts
Tracking	553	11.8	2,955	63.2	1,166	24.9	4,674	100.0	15.8
Not Tracking	722	34.9	1,266	61.1	83	4.0	2,071	100.0	36.3

These data clearly show an important influence of departure attitude on event type. First, the tracking vehicles were much more likely to have nonimpact events than were nontracking vehicles; only four percent of the nontracking vehicles had nonimpact events. Secondly, whether considering all events or only impact events, the nontracking vehicles were much more likely to experience rollovers. This should not be surprising in that rolling over requires a sideward force; nontracking vehicles are subject to such forces. When nonrollover impacts were measured in terms of their proportion of all events, little difference was observed for tracking and nontracking vehicles.

A question can be asked pertaining to the interrelation between departure attitude and departure angle in influencing event type. Table 4-10 provides some data with which to view this question.

The righthand column of Table 4-10 gives the percent of vehicles which were not tracking as a function of departure angle. It clearly shows that, as one might expect, the proportion of vehicles which were not tracking was very low (less than 10%) when departure angles were small; for larger angles, the proportion increased notably, reaching a maximum near 50 percent. Finally, for the very large angles, including T intersection type departures, the proportion of nontracking vehicles was moderately low.

From another viewpoint, a comparison of the departure angle distributions for tracking and nontracking vehicles (second column from the right) shows that tracking vehicles had more departures below eight degrees, whereas nontracking vehicles clearly had more departures in the twelve to 79 degree range. Obviously, there was a highly negative correlation between departure angle and tracking.

Regarding nonimpact events, the table shows that regardless of departure attitude, they occurred more often for small departure angles than for large ones. However, for any departure under 45 degrees, a nonimpact event was much more likely if the vehicle had been tracking.

Whether considering rollovers for all events or for impacts only, the nontracking vehicles, as had been seen earlier, were far more likely to experience rollovers. Attending to the percent of rollovers among impact events for nontracking vehicles, the results show that, if the very large departure angles are excluded, the proportion of rollovers was almost uniform regardless of departure angle. (While the proportion of rollovers was small for departures in the zero to two degree range, there were only eighteen such departures.) A chi-square test of rollovers versus departure angle was not significant ($X_7^2 = 3.04$), thereby failing to demonstrate a dependence of the likelihood of a rollover upon departure angle for nontracking vehicles. It seems reasonable to state that for impacts among nontracking vehicles, the proportion of rollovers was essentially constant at somewhat above 30 percent for any departure angle between three and 45 degrees.

TABLE 4-10 EVENT TYPE FOR DEPARTURE ATTITUDE AND ANGLE (First Event)

Departure Angle (Deg.)	Event Type: Rollover N	Rollover %	Nonrollover N	Nonrollover %	No Impact N	No Impact %	Total N	Total %	% Roll. for Impacts	Departure Angle Distribution	% Not Tracking
TRACKING VEHICLES											
0-2	24	8.7	110	40.0	141	51.3	275	100.0	17.9	7.4	
3-5	54	8.8	329	53.7	230	37.5	613	100.0	14.1	16.6	
6-8	66	7.7	561	65.5	229	26.8	856	100.0	10.5	23.2	
9-11	87	14.5	431	72.0	81	13.5	599	100.0	16.8	16.2	
12-14	28	11.8	178	74.8	32	13.4	238	100.0	13.6	6.4	
15-20	67	14.3	358	76.7	42	9.0	467	100.0	15.8	12.6	
21-29	35	13.8	207	81.5	12	4.7	254	100.0	14.5	6.9	
30-45	33	14.5	180	78.9	15	6.6	228	100.0	15.5	6.2	
46-79	10	12.5	68	85.0	2	2.5	80	100.0	12.8	2.2	
80-90	4	4.6	83	95.4	0	0.0	87	100.0	4.6	2.4	
NONTRACKING VEHICLES											
0-2	3	16.7	11	61.1	4	22.2	18	100.0	21.4	1.2	6.1
3-5	13	29.5	26	59.1	5	11.4	44	100.0	33.3	3.0	6.7
6-8	41	28.7	87	60.8	15	10.5	143	100.0	32.0	9.6	14.3
9-11	67	28.8	159	68.2	7	3.0	233	100.0	29.6	15.7	28.0
12-14	42	30.7	93	67.9	2	1.5	137	100.0	31.1	9.2	36.5
15-20	85	30.8	187	67.8	4	1.4	276	100.0	31.3	18.6	37.1
21-29	85	30.1	192	68.1	5	1.8	282	100.0	30.7	19.0	52.6
30-45	77	35.6	138	63.9	1	0.5	216	100.0	35.8	14.5	48.6
46-79	31	28.7	75	69.4	2	1.9	108	100.0	29.2	7.3	57.4
80-90	2	7.1	26	92.9	0	0.0	28	100.0	7.1	1.9	24.3

If we view rollovers as a proportion of all events, including non-impact events, essentially the same conclusion is reached. That is, there was little to demonstrate an effect of departure angle on the likelihood of rollovers for nontracking vehicles ($X_7^2 = 4.92$). In general, then, it can be concluded for nontracking vehicles, that smaller departure angles were conducive to nonimpact events, but that for all angles less than 45 degrees, departure angle had little, if any, effect on rollover.

Chi-square tests were also conducted for the influence of departure angle on rollovers for tracking vehicles. When taking rollovers as a proportion of all events, the result was significant ($X_7^2 = 31.32$), but when considering rollovers for impact events only, it was not ($X_7^2 = 12.41$). This shows that the primary effect of departure angle was on the likelihood of a non-impact departure rather than a direct influence on the likelihood of rolling over.

Thus, for vehicles which did not get away in the first departure, it can be concluded that when departure attitude was held constant, there was no demonstrated effect of departure angle on the proportion of rollovers for angles up to 45 degrees. For tracking vehicles only, there was an effect when considering rollovers among all events, but this was due to a greater likelihood of nonimpact events for low departure angles.

A remaining question is the influence of departure attitude when departure angle is held constant. The data leave no doubt in this regard. Nonimpact departures occurred approximately three times more often for tracking vehicles for any angle up to 45 degrees (with the exception of the zero to three degree range which had few nontracking vehicles). Whether regarding all events or only impact events, the proportion of rollovers was almost always two to three times as high for nontracking vehicles, irrespective of departure angle.

Thus, it can be concluded that while there was some evidence of an association between departure angle and the likelihood of rolling over, the effect was an indirect one stemming from two factors. First, an increase in departure angle was conducive to a reduction in nonimpact departures; this yielded a complementary increase in rollovers. Second, nontracking vehicles were much more likely to rollover than were tracking vehicles. Because larger departure angles were associated with nontracking vehicles, they were also associated with rollovers. However, when the nonimpact effect was removed and departure attitude was held constant, there was no evidence of an influence of departure angle on rollovers.

In summary, the major effect of an increasing departure angle was a reduction in nonimpact departures. Departure attitude, on the other hand, had an important influence on both nonimpact departures and rollovers.

Finally, by way of providing perspective, in all of the above analysis of event type, there was no instance in which the frequency of rollovers exceeded that of nonrollover impacts.*, ** When considering only impact events, the proportion of rollovers reached maximum values of 48 percent for the second phase of two phase accidents and 46 percent for the third phase of three phase accidents. While the number of nonimpact events was typically well below the number of impact events, in some instances, the proportion of nonimpacts was quite high: tracking vehicles with a departure angle of zero to two degrees -- 51 percent; first departure in two phase accidents -- 73 percent; first departures in three phase accidents -- 79 percent.

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* Excluding the two five phase accidents.

** It is important to note that aside from the analyses of phase number, this result and the others in this discussion apply only to the first phase.

4.2.4 Vehicle Type

Table 4-11 shows the distribution of event types for various car sizes and truck types. First, it can be seen that for ordinary road cars the proportion of rollovers decreased monotonically with car size. While 22 percent of the sports cars and subcompacts rolled, only nine percent of the full sized cars did so. In contrast, utility vehicles (Jeep-type vehicles) rolled approximately three times as often as the ordinary road cars, which had a composite rollover rate of fourteen percent.

The table also shows that while the smaller cars had more nonimpact events than did the larger ones, the effect was not large, having a range of only five percent. Additionally, the proportion of nonimpacts for utility vehicles fell well within the ordinary car range, thereby suggesting no particular propensity for these vehicles regarding nonimpact events.

The last column of the table gives the proportion of rollovers after removing those accidents in which the first event was a nonrollover impact. In this way, the effect of roadside objects (but not terrain) was largely removed. Hence, the column provides a measure of the propensity to rollover versus "getting away". It shows that among the cars which rolled or returned to the road, over fifty percent of the sports cars and subcompacts rolled over. As before, the larger cars had relatively fewer rollovers. Over two-thirds of the utility vehicles rolled over, with only one-third experiencing non-impact events.

Regarding trucks, the results show that no matter how the proportion of rollovers was measured, the values were higher for any truck grouping than for any ordinary road car. Furthermore, light trucks rolled less often than did heavy trucks; they also rolled over less often than did utility vehicles.

TABLE 4-11 EVENT TYPE BY VEHICLE TYPE

(First Event)

Vehicle Type	Rollover		Nonroll Impact		No Impact		Total		% Roll for:	
	N	%	N	%	N	%	N	%	Impact	NOS*
Cars:										
Sports car, or Subcompact	252	22.4	637	56.7	235	20.9	1,124	100.0	28.3	51.7
Compact	191	15.2	837	66.7	227	18.1	1,255	100.0	18.6	45.7
Intermediate	126	10.5	876	72.8	201	16.7	1,203	100.0	12.6	38.5
Full Size	142	8.7	1,237	75.4	262	16.0	1,641	100.0	10.3	35.1
Utility Vehicle	76	40.6	77	41.2	34	18.2	187	100.0	49.7	69.1
Trucks:										
Light Truck	348	26.0	727	54.3	263	19.7	1,338	100.0	32.4	57.0
Van, or Motor Home	91	31.9	134	47.0	60	21.1	285	100.0	40.4	60.3
Heavy Truck										
With Trailer	225	35.8	336	53.4	68	10.8	629	100.0	40.1	76.8
No Trailer	65	40.9	65	40.9	29	18.2	159	100.0	50.0	69.1

* No Object Struck; i.e., rollover or no impact

Among heavy trucks, rollovers occurred somewhat more often for those without trailers. This, however, is to some degree an artifact of the coding process. Because no provisions were made to record jackknifing, a tractor-trailer combination which did jackknife would have experienced nonrollover damage, and as a result, be grouped with the nonroll impacts. It can be seen in the last column where nonroll impacts (and jackknives) were removed, that the heavy trucks with trailers rolled over more often than did those without trailers. Almost as a corollary to this, the data show that the proportion of nonimpact events was lowest (11%) for heavy trucks with trailers.

In general, it is clear that vehicle type had a profound influence on event type for run-off-road accidents.

4.2.5 Shoulder Effects

The effects of shoulder presence and shoulder width on event type were examined. First, by way of background, Table 4-12 gives the proportion of each event types which actually occurred on the shoulder.

TABLE 4-12 EVENT TYPE ON AND OFF THE SHOULDER

(First Event)

	Event Type							
	Rollover		Nonroll Impact		No Impact		Total	
	N	%	N	%	N	%	N	%
On Shoulder	54	3.5	672	13.4	850	60.2	1,576	19.8
Not on Shoulder	1,474	96.5	4,359	86.6	562	39.8	6,395	80.2
TOTAL	1,528	100.0	5,031	100.0	1,412	100.0	7,971	100.0

The righthand column shows that 20 percent of all events occurred on the shoulder. However, there was considerable variation around this value when considering the specific event type. Only four percent of the rollovers occurred on, or were initiated on, the shoulder. Of all nonroll impacts, thirteen percent occurred on the shoulder. Of these 672 impacts, approximately one-third (32%) of the objects struck were guardrails and 23 percent were road structures (e.g., bridge side rails, overpass supports, etc.). Finally, of all nonimpact events, fully sixty percent occurred on shoulders. This means that sixty percent of the nonimpact departure vehicles in phase one departed the road only to the extent of moving onto the shoulder before returning to the road.

Table 4-13 gives event type as a function of shoulder presence and shoulder width. In the lower portions of the table, divided and undivided roads were treated separately. Impacts occurring both on and beyond the shoulder were included. The combined data show the proportion of rollovers were low for one to six foot shoulder widths, nonroll impacts were low in the seven to eight foot range, and nonimpact departures were high in the five to eight foot range. Thus, there were no simple trends observed.

The lower portions of the table were developed because of the likelihood that divided roads had wider shoulders, higher travel speeds, and different event type distributions. Again, however, little in terms of systematic findings were seen. Possible exceptions were a reduction of rollovers for shoulders greater than eight feet and more nonimpact departures for shoulders exceeding four feet on undivided roads, and more rollovers for shoulders at least seven feet wide on divided roads. Close examination of the table, and the lack of similar trends for divided versus undivided roads, however, indicate these possibilities are less than compelling.

TABLE 4-13 EVENT TYPE BY SHOULDER WIDTH

(First Departure - Right Side of Road)

Event Type	No Shoulder		1 - 2		3 - 4		5 - 6		7 - 8		9 - 10		11+	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
- Divided and Undivided Roads -														
Rollover	110	19.0	70	13.3	187	16.8	126	14.6	119	20.7	139	21.1	42	20.8
Nonroll Impact	349	60.3	336	63.8	678	61.1	500	57.9	301	52.3	402	61.1	120	59.4
No Impact	120	20.7	121	23.0	245	22.1	237	27.5	156	27.1	117	17.8	40	19.8
Total	579	100.0	527	100.0	1,110	100.0	863	100.0	576	100.0	658	100.0	202	100.0
- Undivided Roads -														
Rollover	110	19.0	70	13.4	186	16.9	124	14.6	92	18.9	36	14.1	11	10.8
Nonroll Impact	348	60.2	333	63.5	668	60.8	488	57.6	262	53.8	159	62.1	63	61.8
No Impact	120	20.8	121	23.1	245	22.3	235	27.7	133	27.3	61	23.8	28	27.5
Total	578	100.0	524	100.0	1,099	100.0	847	100.0	487	100.0	256	100.0	102	100.0
- Divided Roads -														
Rollover	0	0.0	0	0.0	1	9.1	2	12.5	27	30.3	103	25.6	31	31.0
Nonroll Impact	1	100.0	3	100.0	10	90.9	12	75.0	39	43.8	243	60.4	57	57.0
No Impact	0	0.0	0	0.0	0	0.0	2	12.5	23	25.8	56	13.9	12	12.0
Total	1	100.0	3	100.0	11	100.0	16	100.0	89	100.0	402	100.0	100	100.0

Shoulder Width (ft.)

As a result of a notable absence of systematic relationships between shoulder width and event type, it was concluded (1) that if shoulder width did indeed influence event type, more analysis would be required to uncover the nature of the influence, and (2) that the effect of shoulder width on event type was not of sufficient magnitude to be readily observable in the presence of other variables.

4.2.6 Side Slopes

The following analyses pertain to the effects of height and slope of roadside fill and ditches upon event type. Accidents also occurred on roads with rock cuts, retaining walls, hillsides, etc., but the limited numbers of observations precluded meaningful analysis. Table 4-14 gives event type for road fill versus ditch cut. In order to focus upon the near-road topography, only first events were included.

TABLE 4-14 EVENT TYPE FOR ROAD FILL VERSUS DITCH
(First Event)

Road Type	Rollover		Nonroll Impact		No Impact		Total	% Roll for: Impacts	% Roll for: NOS
Fill	971	23.1	2,497	59.5	731	17.4	4,199	28.0	57.1
Ditch	404	16.1	1,609	64.0	500	19.9	2,513	20.1	44.7

The data show ditch cut roads had relatively fewer rollovers, more nonroll impacts, and slightly more nonimpacts. That there was a greater likelihood of nonroll impacts for ditch cut roads could well have been due to a greater opportunity to collide with a ditch rather than fill, thereby increasing the proportion of nonroll impacts and decreasing the proportion of other event types. This view is supported by the fact that while there was a total of 660 nonroll impacts with ditches, there were only two such impacts with road fill.

One way to remove such effects is to repeat the calculations after removing nonroll impacts from the calculations; this is just what is done in obtaining the results in the NOS column. These results, however, show that when the nonroll impacts were removed, there was still a greater likelihood of rollovers associated with fill than ditches.

In order to clarify the differential effects of ditch cut versus fill, Table 4-15 was developed. It gives the major objects struck for the two types of road construction; rollovers were excluded from the table. In order to emphasize near-road effects, only impacts within twenty feet of the road were included.

TABLE 4-15 OBJECT STRUCK FOR CUT AND FILL
(First Event within 20 feet)

	Road Type			
	Fill		Ditch	
Object Struck	N	%	N	%
Ground	50	3.0	17	1.4
Tree	149	8.9	81	6.5
Wooden Utility Pole	204	12.2	117	9.4
Ditch	105	6.3	220	17.6
Embankment	42	2.5	246	19.7
Fence	139	8.3	91	7.3
Guardrail	254	15.2	30	2.4
Culvert	89	5.3	150	12.0
Trees, Brush	58	3.5	19	1.5
Field Approach	57	3.4	52	4.2
Other	526	31.4	228	18.2
TOTAL	1,673	100.0	1,251	100.0

There were a number of notable differences for the two road types. As one might expect, the proportion of ditches struck was higher for ditch cut roads. While eighteen percent of the impacts involved ditches for these roads, the figure was only six percent for roads built on fill. An even larger difference existed for embankments: twenty percent for ditch cut versus three percent for fill. It is likely that many of these embankments actually represent the far side of the ditch. The final group of objects overrepresented for ditch cut roads were culverts: twelve percent, versus five percent for fill type roads. Thus, to the extent that ditch cuts are characteristic of of roads with embankments, all of the major overrepresented objects for ditch cut roads were directly related to the presence of ditches.

It is also apparent that guardrails were overrepresented among objects struck for roads built on fill. This is likely to reflect a greater use of guardrails when roads are built on fill than for those employing ditches.

After removing nonroll impacts with ditches, embankments, guardrails, and culverts, the remaining number of nonroll impacts was 1,183 for fill and 605 for ditch cut. Table 4-16 gives event types for the two road designs using these residual data plus the original data for rollovers and nonimpacts.

TABLE 4-16 EVENT TYPE FOR ROAD FILL VERSUS DITCH AFTER REMOVING SELECTED NONROLL IMPACTS (First Event)

	Event Type							
Road Type	Rollover		Nonroll Impact		No Impact		Total	
Fill	971	33.7	1,183	41.0	731	25.3	2,885	100.0
Ditch	404	26.8	605	40.1	500	33.1	1,509	100.0

The results show that, after removing objects characteristically associated with cut and fill, the proportion of nonroll impacts was essentially equal for the two road types. Thus, it has been shown that the overrepresentation of nonrollover impacts for ditch cut roads versus roads built on fill was entirely attributable to obstacles related to the specific road design: ditches, embankments, guardrails, and culverts.

The results also show that after removing the effects of differences in objects struck, the proportion of rollovers for fill was still greater than that for ditch cut. This confirms the greater proportion of rollovers for fill in the NOS column for Table 4-14. Thus, the lesser likelihood of rolling over for ditch cut roads was not due to more nonroll impacts, but appears to result from the direct effect on rollover of the differential terrain contour associated with ditch versus fill.

Finally, regarding nonimpact departures, Table 4-14 had shown they were 2.5 percent more likely for ditch cut roads than for roads built on fill. In contrast, Table 4-16 shows the difference was almost eight percent. It appears then that the terrain contour associated with ditches versus fill was more conducive to nonimpacts, but this effect was reduced to a considerable degree by the greater likelihood of nonrollover impacts with ditches, embankments and culverts near ditch cut roads.

The analysis of side slopes continues with an examination of the effects of the magnitude of the slope on event type. Table 4-17 contains this information for both ditch cut and fill.

Considering fill conditions first, the proportion of rollovers showed no consistent relationship with slope. On the other hand, the likelihood of nonrollover impacts increased with increasing slope, while the likelihood of nonimpact events decreased. Thus, the probability of "getting away" decreased with the slope of fill. For those vehicles which did not "get away", the

TABLE 4-17 EVENT TYPE BY SLOPE FOR ROAD FILL AND DITCH

Slope	Rollover		Nonroll Impact		No Impact		Total		% Roll for:	
	N	%	N	%	N	%	N	%	Impacts	NOS
- Fill -										
6:1, or flatter	256	22.4	645	56.4	242	21.2	1,143	100.0	28.4	51.4
4:1	167	22.8	425	57.9	142	19.3	734	100.0	28.2	54.0
3:1	177	25.7	410	59.4	103	14.9	690	100.0	30.2	63.2
2:1	196	19.6	669	67.0	133	13.3	998	100.0	22.7	59.6
1:1	28	24.3	77	67.0	10	8.7	115	100.0	26.7	73.7
- Ditch -										
6:1, or flatter	125	20.6	351	57.9	130	21.5	606	100.0	26.3	49.0
4:1	86	18.8	273	59.7	98	21.4	457	100.0	24.0	46.7
3:1	43	10.7	277	69.1	81	20.2	401	100.0	13.4	34.7
2:1	53	10.1	388	74.0	83	15.8	524	100.0	12.0	39.0
1:1	21	10.4	155	76.7	26	12.9	202	100.0	11.9	44.7

proportion of rollovers, and thus the proportion of nonrollover impacts, varied to some extent with slope, but not in a systematic way (cf. percent rollovers for impacts). The final column on the right shows that for accidents with no object struck, (i.e., for rollovers and nonimpact events only), the proportion of rollovers increased for increasing slope.

Thus, the primary effects of increasing slope of fill were an increase in nonroll impacts and a decrease in nonimpact departures.

The effect of the slope of ditches was somewhat different. As with fill, the proportion of nonimpacts decreased and the proportion of nonroll impacts increased, but with ditches, there was a clear decrease in the proportion of rollovers with increased slope. The increase in nonroll impacts and the decrease in rollovers for steeper slopes undoubtedly reflects the greater likelihood of ditch and ditch-related nonroll impacts discussed earlier.

In summary, as slope increased for either ditch or fill, the proportion of nonimpact departures decreased and the proportion of nonrollover impacts increased. The primary difference between ditch and fill was that, among vehicles with no object struck, rollovers increased with slope of fill, but for ditch cut roads, the proportion of rollovers among all vehicles and among vehicles experiencing impacts decreased with slope. This is a reflection of the dominant effect on nonroll impacts for ditches; they increased almost twenty percent from shallow ditch slopes to steep ones.

Table 4-17 has another interesting aspect. When considering the major effects of slope, the tabulated data appear to reflect some very definite "break points". For fill, the increase in nonrollover impacts appeared as a step function with the increase occurring for slopes steeper than 3:1. The decrease in nonimpact departures occurred in two steps: one for slopes steeper than 4:1, and another for slopes greater than 2:1 (although the 1:1 data contained only 115 observations and are therefore somewhat less reliable).

For ditches, the decreasing proportion of rollovers was due to a step which coincided with the initial increase in nonroll impacts for slopes steeper than 4:1. The reduction in nonimpact departures did not occur until the ditch slope exceeded 3:1.

The next analyses is similar to the previous one, but here the independent variable is height of fill or the depth of ditches rather than their slope. The results appear in Table 4-18.

The primary effect of both height of fill and ditch depth was a positive correlation with the proportion of rollovers. As height of fill increased from two feet to the four to five foot range, the proportion of rollovers increased rapidly. Below two feet and above five feet little change was observed.

Similar results were found for ditches. Here the major increase was observed between three foot ditches and those in the four to five foot range. However, when ditches were deeper than five feet, the proportion of rollovers dropped abruptly. This was apparently due to the increase in nonroll impacts for the deepest ditches. On the other hand, there were only 130 observations for ditches deeper than five feet. To determine if the result was statistically reliable, a chi-square test was run for rollovers versus nonroll impacts cross tabulated with the two deepest ditch categories. The result was statistically significant ($X_1^2 = 7.16$) implying the reduction in rollovers for the six foot and deeper ditches was real.

The results for nonroll impacts and nonimpact departures were not as clear as those for rollovers. Both fill and ditch data showed the proportion of nonroll impacts to be a U-shaped function of height with a minimum in the four to five foot range. Similarly, the proportion of nonimpact departures bore no simple relationship to height. Rather a maximum value was reached for two and three foot heights. No interpretation is offered for these findings.

TABLE 4-18 FIRST EVENT TYPE BY HEIGHT OF FILL OR DEPTH OF DITCH

Height (Feet)	Rollover		Nonroll Impact		No Impact		Total		% Roll for:	
	N	%	N	%	N	%	N	%	Impact	NOS
					- Fill -					
1	40	15.1	172	64.9	53	20.0	265	100.0	18.9	43.0
2	54	15.2	243	68.3	59	16.6	356	100.0	18.2	47.8
3	64	19.1	195	58.2	76	22.7	335	100.0	24.7	45.7
4-5	211	27.2	415	53.4	151	19.4	777	100.0	33.7	58.3
6-10	134	23.3	339	59.1	101	17.6	574	100.0	28.3	57.0
11-20	91	26.4	210	60.9	44	12.8	345	100.0	30.2	67.4
20+	58	24.6	149	63.1	29	12.3	236	100.0	28.0	66.7
					- Ditch -					
1	49	11.7	307	73.3	63	15.0	419	100.0	13.8	43.8
2	78	11.5	441	65.2	157	23.2	676	100.0	15.0	33.2
3	50	12.5	273	68.4	76	19.0	399	100.0	15.5	39.7
4-5	108	25.1	243	56.5	79	18.4	430	100.0	30.8	57.8
6+	19	14.6	89	68.5	22	16.9	130	100.0	17.6	46.3

In summary, the relationships between event type and height were considerably different than those for slope. While increased slope was conducive to a reduction in nonimpact departures, neither increased depth of ditch nor height of fill had a simple effect upon the proportion of nonimpact departures.

Slope had shown a positive correlation with the likelihood of nonroll impacts. In contrast, height of fill and depth of ditch showed no simple relationship with nonroll impacts.

The greatest effect of the height/depth variable was on rollovers. Considering fill height, the proportion of rollovers increased in the two to five foot range, with little effect below or above that range. Similarly, the proportion of rollovers was essentially constant for one, two, and three foot ditches, and then increased notably for four to five foot ditches. Indeed, whether considering slope or height, no important effects upon rollover were observed for either fill or ditch cuts in the two most shallow ranges.

Thus, the height of fill or depth of ditches had their greatest influence on rollovers, while the slope of either fill or ditches was most influential regarding nonroll impacts and nonimpact departures.

It might be noted that the combined effect of height and slope on event type was examined, but no orderly results were found. This may have been due to (1) the reduction in cell frequencies for the increased number of cells, and (2) the inability to use regression analysis without unjustified assumptions as to the form of the functional relationships, noting in particular, the step functions and non-monotonic relationships discussed above.

4.3 Distance-Related Phenomena

4.3.1 Background

The first part of this section contains background material pertaining to various off-road distances. The first table, number 4-19, gives lateral distances to off-road impacts.*

TABLE 4-19 LATERAL DISTANCE TO OFF-ROAD IMPACTS

	First Impact			All Impacts		
Distance (Ft.)	N	%	Cum.%	N	%	Cum.%
0-3	521	8.3	8.3	809	7.2	7.2
4-6	878	13.9	22.2	1352	12.1	19.3
7-9	755	12.0	34.1	1203	10.7	30.0
10-12	1051	16.7	50.8	1709	15.2	45.2
13-15	681	10.8	61.6	1163	10.4	55.6
16-20	782	12.4	74.0	1401	12.5	68.1
21-30	796	12.6	86.6	1665	14.8	82.9
31-40	405	6.4	93.0	828	7.4	90.3
41-60	275	4.4	97.4	659	5.9	96.2
61-100	118	1.9	99.3	312	2.8	98.9
101+	46	0.7	100.0	118	1.1	100.0
Total	6308	100.0		11219	100.0	
Unknown	167			252		
In Road	85			299		
No Impact	1412			1714		
Total	7972			13484		

* Lateral distances were defined as the length of the perpendicular from the road to the point in question. Due to road curvature, the lateral distance was not always equivalent to the actual lateral distance traveled, but it always corresponded to distance from the road.

The table shows that the median distance for first impacts was twelve feet from the road edge. Also, three-fourths of the first impacts were within twenty feet of the road and 87 percent were within thirty feet. Less than one percent of these impacts were beyond 100 feet.

The righthand portion of the table shows that, as expected, the distribution of all impacts reflects somewhat greater distances. Here, the median was in the thirteen to fifteen foot range. Approximately two-thirds were within twenty feet, and 83 percent were within thirty feet. About one percent were beyond 100 feet.

From the lower portions of the table, it can be seen that one percent of the first impacts and two percent of all impacts occurred in the road. These were typically rollovers which occurred after the first departure.

Table 4-20 was developed to provide information pertaining to lateral distances after the first impact. It includes only accidents with at least two events in the first phase; there were 2,538 such accidents. Furthermore, the analysis was restricted to those accidents in which the first two events were off-road impacts with known lateral distances; this gave a total of 2,266 accidents. The table gives the lateral distance for the first and second impacts for these accidents.

The table shows that second impacts tended to be further from the road than were the first impacts. In 1,073, or 47 percent, of these accidents, the second impact was further from the road; in 139, or six percent, the second was closer to the road. Although these results confirm the expected further penetration into the roadside after the first impact, the data also show that there was a tendency for first and second impacts to be equidistant from the road. In every row, the single most frequent cell was the one reflecting the same lateral distance range for both the first and second impacts. Of the 2,266 accidents, 1,054 or 47 percent, had both impacts in the same range.

TABLE 4-20 LATERAL DISTANCES FOR THE FIRST AND SECOND IMPACTS IN PHASE ONE

Lateral Distance for First Impact (ft.)	Lateral Distance for Second Impact (ft.)											
	0-3	4-6	7-9	10-12	13-15	16-20	21-30	31-40	41-60	61-100	101+	Total
0-3	63	29	22	15	9	15	20	9	4	3	1	190
4-6	18	129	36	52	25	28	28	14	15	4	2	351
7-9	6	15	136	41	31	34	34	15	5	4	1	322
10-12	3	9	13	175	40	51	67	13	18	6	3	398
13-15	1	5	6	14	117	34	43	12	11	4	4	251
16-20		3	6	3	7	131	61	21	13	7	3	255
21-30			1	2	3	4	168	43	28	8	1	258
31-40			1	3	2	2	6	49	41	14	1	119
41-60					2			2	51	18	4	77
61-100									1	26	8	35
100+				1							9	10
TOTAL	91	190	221	306	236	299	427	178	187	94	37	2,266

Table 4-21 gives the lateral and longitudinal* components of the vehicle's final rest position. It also gives the total distance traveled by the vehicle from the point of departure to final rest. While lateral distance is a straight line measurement and longitudinal distance was measured along the road, total distance was measured along the vehicle's path.

The median lateral distance to final rest was in the 21 to 30 foot range, as compared to a median of 12 feet for first impact and a median in the 13 to 15 foot range for all impacts.

The median longitudinal distance to final rest was approximately 150 feet. Seven percent of the longitudinal distances were over 500 feet. The total distances traveled were only slightly longer than the longitudinal distance. The median total distance was also near the start of the 151 to 200 foot range. A comparison of cumulative percentages for longitudinal and total distances shows the difference never exceeded four percent. Thus, longitudinal distance to final rest was clearly predominant in determining total distance traveled.

Another distance-related variable is maximum lateral distance. Table 4-22 gives the distribution of the furthest distance from the road for the first phase, and then for the whole accident. It can be seen that for distances greater than 40 feet, the two cumulative distributions are quite similar. The maximum differences between the two occur in the ranges between seven and fifteen feet. Thus, the differences were built up in the first three ranges--from zero to nine feet. Specifically, there were proportionately more limited off-road penetrations in the first phase than for the whole accident. This is a reflection of earlier findings showing a greater proportion of vehicles "getting away" in the first phase than in later ones.

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* Longitudinal distance was measured as the distance along the road from the point of departure to the perpendicular from the point in question to the road. That is, the distance from the point of departure to the line used to define lateral distance.

TABLE 4-21 FINAL REST POSITION

Distance(ft.)	Lateral N	Lateral %	Lateral Cum.%
0-3	530	6.9	6.9
4-6	352	4.6	11.5
7-9	388	5.0	16.5
10-12	614	8.0	24.5
13-15	574	7.5	31.9
16-20	863	11.2	43.1
21-30	1389	18.0	61.1
31-40	1011	13.1	74.3
41-60	1085	14.1	88.4
61-100	634	8.2	96.6
101+	263	3.4	100.0
Total	7703	100.0	

Distance (ft.)	Longitudinal N	Longitudinal %	Longitudinal Cum.%	Total N	Total %	Total Cum.%
0-40	842	11.3	11.3	591	7.9	7.9
41-60	580	7.8	19.1	564	7.5	15.4
61-80	582	7.8	26.9	560	7.5	22.9
81-100	553	7.4	34.3	580	7.7	30.6
101-150	1147	15.4	49.7	1201	16.0	46.6
151-200	847	11.4	61.1	910	12.1	58.7
201-300	1203	16.2	77.3	1231	16.4	75.1
301-400	742	10.0	87.3	824	11.0	86.1
401-500	452	6.1	93.3	484	6.4	92.5
501+	498	6.7	100.0	560	7.5	100.0
	7446	100.0		7505	100.0	

TABLE 4-22 MAXIMUM LATERAL DISTANCE

Distance (ft.)	First Departure N	First Departure %	First Departure Cum.%	Overall N	Overall %	Overall Cum.%
0-3	570	7.6	7.6	153	2.0	2.0
4-6	730	9.7	17.3	356	4.7	6.6
7-9	546	7.3	24.5	381	5.0	11.6
10-12	666	8.9	33.4	636	8.3	19.9
13-15	565	7.5	40.9	617	8.1	28.0
16-20	821	10.9	51.8	944	12.3	40.3
21-30	1210	16.1	67.9	1475	19.3	59.6
31-40	854	11.4	79.3	1074	14.0	73.6
41-60	854	11.4	90.6	1117	14.6	88.2
61-100	487	6.5	97.1	639	8.3	96.6
101+	218	2.9	100.0	263	3.4	100.0
	7521	100.0		7655	100.0	

The overall maximum lateral distance in Table 4-22 can be compared to lateral distance to final rest from Table 4-21. The overall maximum lateral distance should exceed the lateral distance to final rest only to the extent that some vehicles reached their furthest point from the road before the vehicle came to rest. Contrasting the two distributions, it can be seen that the only difference of any magnitude occurred in the very first distance range. While seven percent of the vehicles came to rest within three feet of the road, only two percent traveled no further than three feet from the road. This reflects vehicles striking objects near the road and rebounding or being deflected to a final rest nearer the road. It does not reflect vehicles traveling off the road and then intentionally being driven back to the road edge; such instances were few in number, and when they did occur, final rest was recorded either as where the vehicle initially stopped or as unknown.

Table 4-23 gives the maximum lateral distance in the first phase, but only for vehicles with no impacts in that phase. It shows that of the vehicles which "got away" in the first phase, 31 percent penetrated the roadside by three feet or less. Sixty-two percent penetrated no more than six feet, and 78 percent penetrated no more than nine feet. Fully 88 percent penetrated no more than twelve feet; beyond that, the incremental percentages were quite small.

TABLE 4-23 MAXIMUM LATERAL DISTANCE FOR NON-IMPACT EVENTS

(First Phase)

Distance(ft.)	Frequency	Percent	Cumulative Percent
0-3	376	30.6	30.6
4-6	390	31.7	62.3
7-9	192	15.6	77.9
10-12	121	9.8	87.7
13-15	56	4.6	92.3
16-20	37	3.0	95.3
21-30	26	2.1	97.4
31-40	11	0.9	98.3
41-60	11	0.9	99.2
61-100	8	0.7	99.8
100+	2	0.2	100.0
TOTAL	1,230	100.0	

4.3.2 Borders and Border Offset

Table 4-24 gives distributions of border type. A border was defined to be a generally nontraversable obstacle which extended through at least 50 percent of the vehicle's off-road path.* Borders were determined from the accident pictures. In many instances, the pictures did not provide a useful view of the roadside; hence, borders were recorded only for a limited number of accidents. Finally, borders were coded only for roadsides into which departures occurred; if departures occurred on both sides, the two borders were coded separately.

TABLE 4-24 BORDER TYPE

	First Departure Side		Second Departure Side	
	N	%	N	%
Terrain	1171	35.1	204	37.8
Natural Objects	1674	50.2	251	46.6
Fixed Objects	147	4.4	17	3.2
Temporary Objects	2	0.1	0	0.0
Permanent Barriers	280	8.4	45	8.3
Attenuators	1	0.0	0	0.0
Road Structures	57	1.7	22	4.1
TOTAL	3332	100.0	539	100.0

* For example, if a vehicle traveled a longitudinal distance of 50 feet off the road, an applicable border was required to extend at least 25 feet into the area defined by a perpendicular from the road at the point of departure to another perpendicular from the road 50 feet downstream.

A comparison of the distributions for the first and second departure sides shows very little difference. The most frequent borders were natural objects, typically trees, or trees and brush. Roughly one-half of the borders were such natural objects. The second most frequent general border type was terrain. This classification accounted for over one-third of the borders; it included ditches, embankments, water, etc. Eight percent of the borders were permanent barriers such as guardrails, guard posts, or concrete barriers. Approximately four percent of the borders were fixed objects including primarily fences, but also buildings. Road structures such as bridge side rails and overpass supports accounted for approximately two percent of the borders.

Table 4-25 gives border offset distributions for each border type. Road structures had the smallest offsets with 93 percent being within ten feet of the road edge. Permanent barriers were also close to the roads; three-fourths had offsets within ten feet, and 97 percent were within 20 feet. Next were terrain obstacles with a median offset near 11 or 12 feet. Natural objects were more distal. Only twelve percent were within ten feet, the median offset was 21 or 22 feet, and approximately 10 percent were beyond 60 feet. Most distant were the fixed objects. Less than ten percent were within ten feet, the median offset was 40 feet, and over one-fourth were beyond 60 feet.

In the next analysis, event type was cross-tabulated with border offset. The results are in Table 4-26. None of the three event types bore a simple monotonic relationship to border offset. The likelihood of a rollover increased with offset but there was a notable decrease in the 61 to 100 foot range. The likelihood of nonrollover impacts moved opposite to that of rollovers. It showed a generally decreasing trend with a peak in the 61 to 100 foot range. The first order effects seemed reasonable. If a border acted primarily as a barrier, the greater the offset, the fewer the vehicles reaching it, and the fewer the nonrollover impacts. This, in turn, would allow greater opportunity for rollovers.

TABLE 4-25 BORDER OFFSET BY BORDER TYPE

	Terrain		Natural Objects		Fixed Objects		Temporary Objects		Permanent Barriers		Attenuators		Road Structures	
Offset(ft.)	N	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%
0 - 10	487	42.9	182	12.4	8	8.9	2	28.6	203	75.2	0	0.0	53	93.0
11 - 20	340	72.9	473	44.7	9	18.9	0	28.6	59	97.0	0	0.0	3	98.2
21 - 30	142	85.4	323	66.8	12	32.2	0	28.6	4	98.5	0	0.0	1	100.0
31 - 40	42	89.2	191	79.8	16	50.0	0	28.6	3	99.6	0	0.0	0	100.0
41 - 60	39	92.6	162	90.9	20	72.2	1	42.9	0	99.6	0	0.0	0	100.0
61 - 100	26	94.9	72	95.8	19	93.3	4	100.0	0	99.6	0	0.0	0	100.0
101 - 300	16	96.3	28	97.7	5	98.9	0	100.0	1	100.0	0	0.0	0	100.0
301 +	42	100.0	33	100.0	1	100.0	0	100.0	0	100.0	0	0.0	0	100.0
TOTAL	1134		1464		90		7		270		0		57	

TABLE 4-26 EVENT TYPE BY BORDER OFFSET

(First Phase)

Border Offset (ft.)	Rollover		Non-Roll Impact		No Impact		Total		% Roll for:	
	N	%	N	%	N	%	N	%	Impact	NOS
0 - 10	60	6.4	754	80.7	120	12.8	934	100.0	7.4	33.3
11 - 20	120	13.6	641	72.4	124	14.0	885	100.0	15.8	49.2
21 - 30	80	16.6	319	66.2	83	17.2	482	100.0	20.1	49.1
31 - 40	47	18.7	166	65.9	39	15.5	252	100.0	22.1	54.7
41 - 60	52	23.4	144	64.9	26	11.7	222	100.0	26.5	66.7
61 - 100	18	14.8	89	73.0	15	12.3	122	100.0	16.8	54.5
101 - 300	13	26.0	27	54.0	10	20.0	50	100.0	32.5	56.5
301 +	171	36.3	180	38.2	120	25.5	471	100.0	48.7	58.8

The reason for the trend reversal in the 61 to 100 foot range, however, was not clear. One contributing factor may be indicated by the data in Table 4-25. By computing proportions within rows, it can be determined the proportion of borders in the terrain class was highest in the first and last offset zones; it was lowest for offsets in the 31 to 100 foot range. To the extent that borders consisting of objects are conducive to nonroll impacts and terrain borders are conducive to rollovers, this provides a partial basis for the trend reversals.

Regarding the nonimpact departures, their relative frequency increased up to offsets in the 21 to 30 foot range, then decreased, only to increase beyond the 100 foot range. While one might have expected to see a greater increase in nonimpacts with increasing border offset, earlier results (Table 4-23) showed that roughly 80 percent of the nonimpact vehicles (in the first phase) had maximum lateral distances within ten feet of the road. Thus, moderate increases in the border offset beyond that could be expected to have limited effects.

In order to better understand the effects of border offset on event type, an analysis was run to determine impact type as a function of lateral distance and border offset. The initial results are in Table 4-27, and a summary is given in Table 4-28.

Table 4-28 shows that of the impacts occurring between the road and the border, one-third were rollovers and two-thirds were nonrollover impacts. For impacts occurring at or near the border, fewer of them were rollovers; over 90 percent were nonroll impacts. Beyond the border, there was a small decrease in the proportion of nonroll impacts. Finally, the results show that for the tabulated impacts, almost 40 percent occurred before the border, 47 percent occurred at the border, and only 14 percent occurred beyond the border.

TABLE 4-27 IMPACT TYPE BY LATERAL DISTANCE AND BORDER OFFSET

(First Event)

Border Offset (ft.)	Impact Type	Lateral Distance (ft.)					
		N	%	N	%	N	%
0 - 10		--		0 - 9		10 +	
	Roll	--		29	5.1	29	12.3
	NRI*	--		535	94.9	206	87.7
	Total	--		564	100.0	235	100.0
11 - 20		0 - 9		10 - 20		21 +	
	Roll	45	25.9	52	10.9	18	18.4
	NRI	129	74.1	425	89.1	80	81.6
	Total	174	100.0	477	100.0	98	100.0
21 - 30		0 - 20		21 - 30		31 +	
	Roll	49	22.1	23	17.0	6	15.4
	NRI	173	77.9	112	83.0	33	84.6
	Total	222	100.0	135	100.0	39	100.0
31 - 40		0 - 30		31 - 40		41 +	
	Roll	37	30.3	5	8.8	4	16.7
	NRI	85	69.7	52	91.2	20	83.3
	Total	122	100.0	57	100.0	24	100.0
41 - 60		0 - 40		41 - 60		60 +	
	Roll	42	30.4	9	17.6	0	0.0
	NRI	96	69.6	42	82.4	5	100.0
	Total	138	100.0	51	100.0	5	100.0
61 - 100		0 - 60		61 - 100		101 +	
	Roll	16	20.5	2	8.0	0	0.0
	NRI	62	79.5	23	92.0	2	100.0
	Total	78	100.0	25	100.0	2	100.0
101 +		0 - 100		100 +		-	
	Roll	171	47.8	3	27.3	-	
	NRI	187	52.2	8	72.7	-	
	Total	358	100.0	11	100.0	-	

*Nonroll Impact

TABLE 4-28 IMPACT TYPE BY LATERAL DISTANCE RELATIVE TO BORDER OFFSET

(First Event)

Impact Type	Lateral Distance Relative to Offset					
	Less Than		Equal to		Greater Than	
	N	%	N	%	N	%
Rollover	360	33.0	123	9.3	57	14.1
Nonroll Impact	732	67.0	1197	90.7	346	85.9
TOTAL	1092	100.0	1320	100.0	403	100.0

Thus, almost one-half of the impacts occurred at the border. Among these, over 90 percent were nonrollover impacts. Less than one-sixth of the impacts occurred beyond the border. Clearly, the border had an important effect on off-road behavior.

The reduction in nonrollover impacts versus rollovers beyond the border is probably due to the fact that there are two general kinds of borders. The first type is a line border; the culture is essentially the same on both sides of it. A steep ditch could be an example. The second type is an edge border; it signifies a change in roadside culture which continues beyond the border itself. An example is a grove of trees. The likelihood that an impact is a nonroll impact is likely to remain constant beyond edge borders, but it is likely to decrease beyond line borders. Since both types were present, one could have expected a limited decrease in nonrollover impacts beyond the border.

The previous analysis was focused upon impacts relative to border offset. The next analysis is concerned with the effects of border offset on maximum lateral distance. The results are in Table 4-29 which gives the distributions of the furthest point from the road relative to the border offset. First, the righthand column shows that the border offset was a true obstacle. Vehicles penetrated the roadside as far as the border more often than either stopping short of it or traveling beyond it; only 29 percent of the vehicles went beyond the border.

In a sense, the border acts like a magnet. The bottom of the table gives the median maximum lateral distance for each offset interval. They show that for offsets up to 60 feet, the median penetration into the roadside was equivalent to the border offset. Thus, there was a tendency for vehicles to go as far as the border but no further. However, it can also be seen in the first row that the proportion of vehicles which did not reach the border increased with offset. Conversely, the proportion of vehicles traveling beyond the border decreased with offset.

TABLE 4-29 MAXIMUM LATERAL DISTANCE (MLD) RELATIVE TO BORDER OFFSET (BO)

(First Phase)

Relationship	Border Offset (feet) 0-10		11-20		21-30		31-40		41-60		61-100		101+		All	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
MLD < BO	-	-	132	15.3	150	31.8	90	36.1	90	41.1	61	51.3	421	90.1	944	28.6
MLD ~ BO	474	52.3	459	53.2	176	37.3	81	32.5	96	43.8	49	41.2	46	9.9	1,381	41.9
MLD > BO	433	47.7	272	31.5	146	30.9	78	31.3	33	15.1	9	7.6	-	-	971	29.5
TOTAL	907	100.0	863	100.0	472	100.0	249	100.0	219	100.0	119	100.0	467	100.0	3,296	100.0
Median MLD Range (feet)	7-9		16-20		21-30		31-40		41-60		41-60		31-40			

Thus, the border appears to operate as one might expect. Its effect is like that of a major obstacle among minor ones. Many vehicles reach it; few go beyond it. As the offset increases, the minor obstacles take their toll, and the proportion of vehicles reaching, or going beyond, it decreases.

4.3.3 Wooden Utility Poles

While the previous discussion pertained to relatively nontraversable borders, utility poles can be viewed as semi-traversable borders. Table 4-30 gives distributions of objects struck as a function of pole offset. Only accidents occurring in the presence of wooden utility poles were included. There were 2,474 accidents where wooden utility poles were found in the accident pictures; of these, 1,879 had known pole offsets.

The results in Table 4-30 reflect all events in phase one. While this precludes independence of data points for those accidents involving two or more first phase events, the use of the first event only would have biased the results in that increasing offset would have given greater opportunity for other objects to be struck first, thereby magnifying the effect of offset.

The results clearly show that the proportion of first phase objects struck which were poles decreased monotonically with pole offset. Ignoring the last interval because of its unlimited range, the proportion of pole strikes decreased an average of 5.0 percent for each successive six foot offset interval.

It might be noted that two other groups of objects were also impacted less frequently with increasing pole offset. They were trees (usually a lone tree) and trees or brush (usually brush or a clump of small trees). It is likely that this reflects a right-of-way clear of trees between the road and the pole line.

TABLE 4-30 OBJECT STRUCK BY POLE OFFSET
(All Events - First Phase)

Object Struck	Pole Offset (ft.) 1-6		7-12		13-18		19-24		25-30		31+	
	N	%	N	%	N	%	N	%	N	%	N	%
No Impact	19	4.8	75	8.6	46	9.3	39	9.9	25	10.7	56	13.4
Ground	58	14.6	134	15.3	91	18.3	80	20.3	56	24.0	129	30.8
Tree	27	6.8	58	6.6	33	6.7	19	4.8	7	3.0	15	3.6
WUP*	142	35.9	279	31.8	119	24.0	80	20.3	37	15.9	40	9.5
Ditch	9	2.3	29	3.3	27	5.4	31	7.8	18	7.7	25	6.0
Embankment	16	4.0	44	5.0	16	3.2	23	5.8	13	5.6	8	1.9
Fence	30	7.6	73	8.3	39	7.9	34	8.6	19	8.2	44	10.5
Guardrail	2	0.5	9	1.0	6	1.2	4	1.0	4	1.7	4	1.0
Culvert	6	1.5	28	3.2	16	3.2	14	3.5	10	4.3	17	4.1
Trees, Brush	17	4.3	30	3.4	17	3.4	6	1.5	5	2.1	6	1.4
Field Approach	1	0.3	5	0.6	4	0.8	6	1.5	8	3.4	25	6.0
Other	69	17.4	112	12.8	82	16.5	59	14.9	31	13.3	50	11.9
Total	396	100.0	876	100.0	496	100.0	395	100.0	233	100.0	419	100.0
No Impact + WUP	161	40.7	354	40.4	165	33.3	119	30.1	62	26.6	96	22.9

*Wooden Utility Pole

As the likelihood of hitting poles, trees, or trees and brush decreased, there was a complementary increase in other objects struck. Most notable were ground (reflecting mostly rollovers) and ditches. There was also an increase in no impacts in the first phase with increasing pole (and tree) offset. With poles in the one to six foot range, the proportion of no impacts was five percent; when pole offset was greater than 30 feet, the proportion was thirteen percent.

By adding the proportions for wooden utility poles to those for no impacts, it can be determined whether changes in one reflect changes in the other; these sums appear at the bottom of Table 4-30. The resultant proportions are constant for the first two offset intervals and then decrease monotonically. Thus, the increased offset from the first interval to the second had the effect of decreasing pole strikes and increasing no impacts by a complementary amount; as fewer poles were hit, more vehicles "got away". For each successive offset interval, however, the proportions decreased. For these offsets, the decreased proportions of pole strikes could not be explained in terms of vehicles "getting away". In summary, the proportion of pole impacts decreased with each successive increase in pole offset. For offsets of twelve feet or less, the reduction in pole impacts was matched by an increase in nonimpact departures.

A second analysis was performed to determine if pole offset was a factor in determining impact speed for pole strikes. The results are in Table 4-31.

TABLE 4-31 IMPACT SPEED BY POLE OFFSET

(Wooden Utility Pole Impacts Only)

Pole Offset (ft.)	N	Mean Impact Speed (MPH)
1-6	118	29.2
7-12	216	29.8
13-18	88	28.7
19-24	54	28.8
25-30	23	23.3
31+	23	24.5

The results show a clear decrease in impact speed with increasing pole offset. However, it is important to see that essentially no change occurred until the poles were 25 feet from the road. If the relationship is accurately portrayed by the data at hand, a very large pole offset would be required to reduce impact speed and attendant impact severity.

4.3.4 Clear Zones

Two analyses were performed to examine the effects of hypothetical clear zones. The analyses are concerned with clear zone effects on the occurrence of off-road impacts and then upon impact speed.

4.3.4.1 Nonimpact Departures

The purpose of the first analysis was to determine the effect of a clear zone on vehicles getting away without impact in the first departure. As discussed earlier, a nonimpact event in the first departure is a necessary condition for the avoidance of impacts if a vehicle leaves the road. While a nonimpact event obviously does not assure that the vehicle will get away unscathed, it does present the opportunity to do so.

Some of the previous analyses relate to the topic hand. For example, it has been shown that the proportion of nonimpact events increased with pole offset, increased moderately with border offset, and bore no clear relationship with shoulder width. However, none of these factors (borders, poles, shoulders) assure a truly clear zone.

The clear zone analysis involved off-road zones parallel to the road starting at distance L (low) from the road, and extending to distance H (high) from the road. Each successive zone was analyzed as if it were a clear zone; that is, vehicles would behave as they actually did in the accidents studied except that no impacts (rollovers or nonroll impacts) would occur.

The second assumption for the analysis is that the path of a departing vehicle is U-shaped, or a part thereof. That is, a vehicle departs the road heading away from it. If, at any point along its path, the vehicle turns back toward the road, then the remainder of its path will be toward the road. Since the only data used reflect vehicle paths up to the first impact or the paths of vehicles experiencing no impact, the assumption is quite reasonable.*

The data were those reflecting vehicles for which lateral distance to the first impact (I), maximum lateral distance (M), and vehicle direction immediately before impact were known. One further restriction was placed on the data used: those vehicles which were traveling parallel to the road at impact were excluded. This was done because of the ambiguity in expected direction of further travel if the impact had not occurred. This reduced the available data from 7,333 vehicles to 6,949 vehicles. The following discussion describes the data in Table 4-32.

There were 6,949 vehicles which departed the road and entered the first zone (L=0, H=3). For each zone, the number of vehicles entering the L side without a previous impact is given by the number of vehicles whose maximum lateral distance was in or beyond the zone (M≥L), and which had (1) a nonimpact departure (NI), or (2) an impact in or beyond the zone (I≥L), or (3) an impact between L and the road while it was traveling toward (T) the road. For the first zone, the respective number of vehicles were 1,230, 5,719, and 0, giving the total of 6,949 vehicles first entering the 0-3 zone from the L side.

The vehicles entering any L-H zone from the L side without any previous impact either experienced an impact in the zone, turned back to the area before L, or continued to the area beyond H. There were two groups of vehicles which turned back. Both had a maximum lateral distance in the L-H zone; i.e.,

* The following discussion is quite detailed. Some readers may prefer to skip to the results in Figure 4-1 and the related discussion.

Actual Raw Data

Clear Zone L-H	Entered L Side: M≥L NI	Entered L Side: M≥L I≥L	Entered L Side: M≥L I<L, T	Σ	Turned Back: L≤M≤H I<L, T	Turned Back: L≤M≤H NI	Σ	Impacts in Zone: L≤M≤H L≤I≤H	Impacts in Zone: M>H, A L≤I≤H	Σ	No Impact in Zone: By Subtraction	% Turned Back Among No Impacts
0-3	1,230	5,719	0	6,949	0	376	376	149	283	432	6,517	5.77
4-6	854	5,272	15	6,141	6	390	396	207	527	734	5,407	7.32
7-9	464	4,518	29	5,011	5	192	197	199	443	642	4,369	4.51
10-12	272	3,859	41	4,172	10	121	131	288	658	946	3,226	4.06
13-15	151	2,898	46	3,095	16	56	72	206	419	625	2,470	2.91
16-20	95	2,264	39	2,398	19	37	56	244	452	696	1,702	3.29
21-30	58	1,558	30	1,646	18	26	44	351	401	752	894	4.92
31-40	32	803	15	850	9	11	20	189	198	387	463	4.32
41-60	21	415	7	443	7	11	18	150	111	261	182	9.89
61-100	10	154	0	164	0	8	8	80	31	111	53	15.09
100+	2	43	0	45	0	2	2	43	0	43	2	100.00

($L \leq M \leq H$). The first group had an impact between L and the road and were traveling toward the road ($I<L$, T). Of course, for the 0-3 zone, there were no such vehicles. The second group of vehicles turning back returned to the road without impact (NI); there were 376 such vehicles in the first zone. Thus, of the 6,949 vehicles entering the 0-3 zone, 0 + 376 = 376 turned back.

The number of impacts in any L-H zone, among vehicles without previous impact which entered the L side, consisted of two groups. The first group traveled no further than H; they are characterized by $L \leq I \leq H$, and $L \leq M \leq H$. There were 149 such vehicles in the first zone. The second group involved vehicles with their first impact in L-H, but with further travel beyond H ($M>H$). To distinguish these vehicles from those traveling beyond H and returning to an impact in L-H, only those vehicles headed away (A) from the road at impact were included. There were 283 such vehicles, giving a total of 432 first impacts in the 0-3 zone among vehicles entering the L side.

Thus, 6,949 entered the 0-3 zone from the road; 432 had impacts there; and 376 turned back to the road without impact. As a result, 6,517 vehicles had no impact in the first zone, and 6,141 entered the second (4-6) zone. Table 4-32 contains these data for all eleven computational zones from 0-3 to 101 and above.

To this point, nothing has been said about clear zones. The data presented reflect actual observations including the fact that, of the 6,949 vehicles, 1,230 got away even though there was no clear zone.

Now we can proceed to examine the expected effects of hypothetical clear zones. If a zone is clear, no impacts will occur there. Secondly, and as a direct result, more vehicles will either turn back or go on beyond the zone. Because any zone being clear implies all previous zones are clear,

any vehicle which turns back will get away; that is, it will return to the road without impact. Thus, in a clear zone, a vehicle either turns back and gets away, or it goes on to the next zone.*

The next step, then, is to estimate the proportion of vehicles entering the L side which would have turned back. Since it was assumed that in a clear zone those vehicles actually experiencing impacts would have behaved like those which actually did not, the behavior of all vehicles can be simulated by those which had no impact in the zone. Specifically, the proportion of vehicles turning back, had the zone been clear, is given by the proportion of vehicles turning back among those vehicles with no impact in the zone. For the first zone, this is 376÷6,517, or 5.77 percent. For the 4-6 zone, it is 396÷5,047, or 7.32 percent. Etc.

The analysis continues in Table 4-33. The first tabular column contains the proportion of vehicles entering the L side of each zone which would have gotten away. The second column gives the number of vehicles entering the zone if the previous zone had been clear. For the first zone, this is the same as the number actually entering it from the road. For each successive zone, the number of vehicles entering is given by the number entering the previous zone minus those which got away. In this way, the number entering, now a theoretical value, reflects the fact that when previous zones are clear, more vehicles will pass on through to the more distal ones.

For the 0-3 zone, 6,949 vehicles entered from the L side, and 5.77 percent of them, or 401, would have gotten away. However, before completing the analysis, another factor must be taken into account. To this point, we have considered only those vehicles which entered each zone from the L side;

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* If the data included vehicles which actually got away with no impacts in any phase, then some of them would have come to a stop in a hypothetical clear zone. Such vehicles would have fallen into the (L≤M≤H, NI) group, and would be counted, appropriately, among those which had turned back.

TABLE 4-33 CLEAR ZONE EFFECTS FOR ALL VEHICLES

L-H (ft.)	% Turned Back	Revised Total Entered	Get Away if Entered L	Get Away if Entered H	Get Away	Predicted Get Away: L=0 to H N	Predicted Get Away: L=0 to H %	Increase Per Zone %	Increase Per Foot %
None						1,230	17.7		
0-3	5.77	6,949	401	15	416	1,270	18.3	0.6	0.20
4-6	7.32	6,533	478	20	498	1,378	19.8	1.6	0.53
7-9	4.51	6,035	272	17	289	1,475	21.2	1.4	0.47
10-12	4.06	5,746	233	15	248	1,602	23.1	1.8	0.60
13-15	2.91	5,498	160	9	169	1,715	24.7	1.6	0.53
16-20	3.29	5,329	175	10	185	1,863	26.8	2.1	0.42
21-30	4.92	5,144	253	3	256	2,093	30.1	3.3	0.33
31-40	4.32	4,888	211	1	212	2,294	33.0	2.9	0.29
41-60	9.89	4,676	462	0	462	2,745	39.5	6.5	0.33
61-100	15.09	4,214	636	0	636	3,373	48.5	9.0	0.23
101+	100.00	3,578	3,578	0	3,578	6,949	100.0	51.5	

that is, those vehicles entering a zone for the first time. There are, however, also those vehicles which passed through a zone and reached their maximum lateral distance, only to return through the H side and experience their first impact within the zone. These vehicles are characterized by M>H, L≤I≤H, T. Had the zone been clear, these vehicles would also have gotten away. There were fifteen such vehicles for the first zone. Therefore, a final total of 416 (401 + 15) vehicles would have gotten away had the first zone been clear.*

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* Although these fifteen vehicles actually went on to the next zone while headed away from the road, they were not included as such in the previous calculations. This is because these vehicles actually passed through more distal zones without impact, even though they were not clear. As such, they were not candidates for getting away in those zones. Each vehicle can get away only once, and since these vehicles had their first impacts in the 0-3 zone, they could get away only from the 0-3 zone. Of course, the same applies to any L-H zone for returning vehicles which had their first impacts between L and H. Thus, in the initial calculations in Table 4-32, these vehicles were included among the L side entries as part of the set (M≥L, I≥L), but excluded from those vehicles having impacts in the zone. In this way, their first passage through a zone was correctly included in the denominator, but excluded in the numerator, of percent of vehicles turning back.

On the other hand, it would have been erroneous to include H entries in these initial calculations since these vehicles could not have been expected to go beyond H had no impact occurred. (Actually, they could have been included but the analysis would have become more complicated, and the results would not have differed from those given here.) Had these vehicles been included earlier, without modification of the analysis, more vehicles would have been estimated to get away. The end result, when considering a totally clear roadside, would have shown more "get aways" than vehicles.

Thus, for each vehicle which entered the 0-3 zone at least once, 6,533 (6,949-416) would have gone on to the 4-6 zone.* Had it been clear, 7.32 percent, or 478, would have gotten away upon first entering the zone, and another 20 would have gotten away upon returning to it. Thus, a total of 498 vehicles would have gotten away in the 4-6 zone and 6,035 would have gone on to 7-9 zone. This logic was applied to all succeeding zones, ending up with 3,578 vehicles entering the zone beyond 100 feet. All of them would have gotten away had this (infinite) zone been clear.

It is important to recall, however, that 1,230 vehicles actually got away with no clear zones. To reflect the change which would have been induced by clear zones, the number of vehicles actually getting away (those labeled L≤M≤H, NI in Table 4-32) were subtracted from the total getting away for each zone. There were 40 (416-376) in the 0-3 zone, 108 (498-390) in the 4-6 zone, etc. Then, starting with 1,230, the accumulated number of vehicles getting away was tabulated: 1,230+40 = 1,270; 1,270+108 = 1,378; etc. Cumulative percentages are given in the table, followed by the incremental percent for each zone. Finally, this increment in the proportion of vehicles getting away with each successive zone was divided by the zone width to get the increase in proportion of vehicles expected to get away as a result of a one foot increase in clear zone width.

Thus, 1,230, or 17.7 percent, of the vehicles actually got away with no clear zone. If the 0-3 zone had been clear, 18.3 percent would have gotten away, an increase of only 0.6 percent. Had the roadside been cleared another three feet an additional 1.6 percent would have gotten away, making the total 19.8 percent, an increment from no clear zone of 2.1 percent.

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* Fifteen more vehicles would have gone on to the 4-6 zone, but we are concerned only with those which would have been candidates for getting away.

The percent of vehicles getting away, among all departing vehicles, is plotted as a function of clear zone width from zero to H in Figure 4-1. It shows that within small error, the percent of vehicles getting away would increase essentially linearly with clear zone width. (A linear fit of the ten unweighted data points gave a correlation coefficient of .978.) Thus, there appears to be no spectacular break point where a clear zone would suddenly become effective or reach an important point of diminishing returns, at least within the first 100 feet.

Nonetheless, the last column in Table 4-33 does show some variation in the incremental effects of additional clear space. Basically, the effects would be greatest near the 10-12 zone where the average increase in vehicles getting away was 0.6 percent per foot. The calculated effects were least for the most extreme zones: 0-3 and 61-100 feet.

Since any real clear zone is likely to start at the road edge (this was assumed in the analysis), it was of interest to determine the zone width for which the percentage of vehicles getting away per foot of total clearance was maximized. The calculation involved subtracting 17.7 percent from the cumulative percent and dividing by H. The results are in Table 4-34.

The findings show that, although the maximum incremental benefit had previously been shown to occur in the 10-12 zone, this was not true for the 0-12 zone. Specifically, since the percentage for the 13-15 zone was greater than that for the 0-12 zone, when the 13-15 value was averaged in, there was a minor improvement. The findings show that the maximum benefit, in terms of vehicles getting away divided by the zone width, occurred for the fifteen foot zone and was only marginally lower for twenty foot zone. Thus, maximizing the benefit/cost ratio would imply a clear zone of width from 15 to 20 feet. Remember, however, the results in Figure 4-1 showed an almost linear increase in get aways up to 100 feet. Thus, while benefits per foot of clearance would be maximized near 15 or 20 feet, further clearance would yield further benefits.

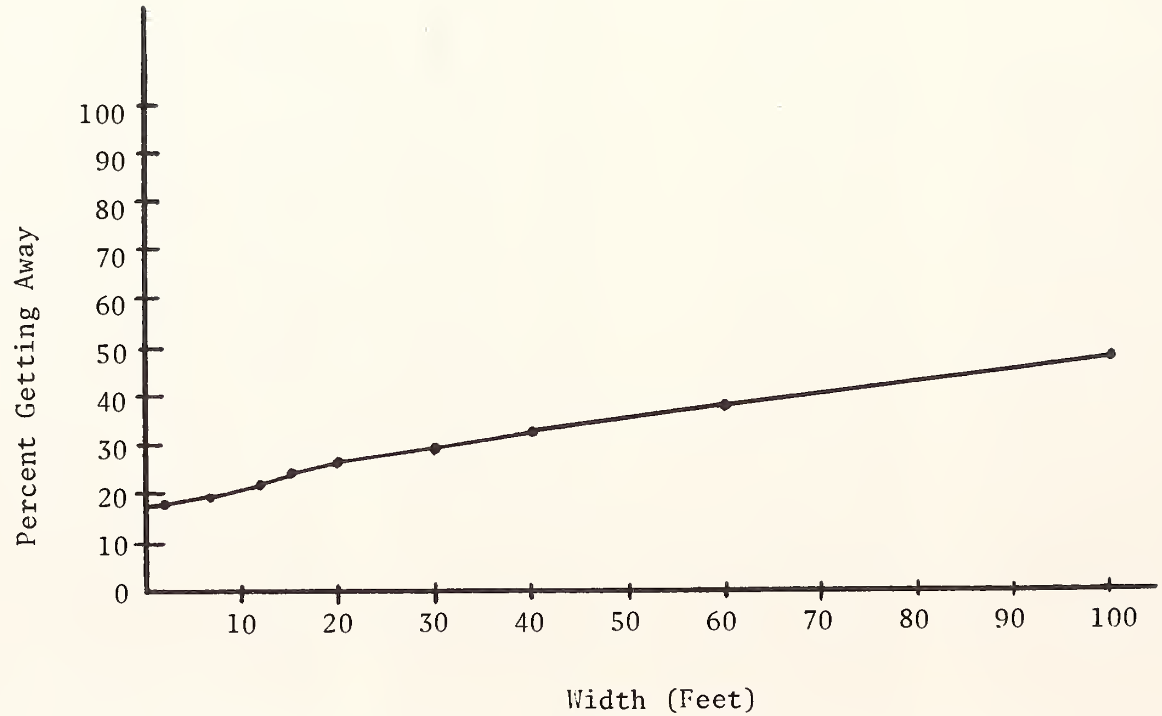

FIGURE 4-1 PERCENT OF ALL DEPARTING VEHICLES WHICH WOULD GET AWAY AS A FUNCTION OF CLEAR ZONE WIDTH

TABLE 4-34 PERCENT OF VEHICLES GETTING AWAY PER FOOT BY ROADSIDE CLEAR ZONE WIDTH

Width (ft.)	Percent Getting Away (Minus 17.7%)	Percent Getting Away Per Foot
3	0.6	0.20
6	2.1	0.35
9	3.5	0.39
12	5.4	0.45
15	7.0	0.47
20	9.1	0.46
30	12.4	0.41
40	15.3	0.38
60	21.8	0.37
100	30.8	0.31

Several precautions are advisable in interpreting these findings.

The reader is reminded that although it would have been highly desirable to estimate the effects of clear zones on accident avoidance, this was not possible with the current data set. Rather, the proportion of vehicles getting away refers only to vehicles avoiding impact in the first departure and thereby being presented with an opportunity to get away upon returning to the road.

Furthermore, the reader is cautioned to bear in mind that these calculations pertain only to perfect clear zones where the probability of

rollovers and nonroll impacts was assumed to be zero. In this sense, the results reflect maximum possible benefits.*

Finally, it is likely that off-road factors influencing lateral distance were correlated with on-road factors. For example, border offset may be correlated with horizontal and vertical alignment which had previously been shown to influence departure characteristics. This, in turn, could be expected to influence off-road behavior. Thus, the effects of other roadway characteristics could well have been confounded with clear zone effects in the above analysis. Hence, the results do not reflect only the influence of clear zones, but also the influence of other factors determining lateral distances. As such, the results show expected effects averaged over the kinds of roads and roadside represented in the sample. As with most findings in the study, they may or may not apply to specific locations.

4.3.4.2 Impact Speeds

In the next analysis, which is far less tedious than the last one, the effects of clear zones on impact speed were examined. A clear zone was characterized as it was in the previous analysis: the vehicles in a clear zone would behave in the same way as the observed vehicles, except that no impacts would occur within the zone.

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* If one wanted to assume a nonzero probability, P, this could be done by multiplying the percent turned back in Table 4-33 by 1-P, and recalculating the number getting away as well as each successive "revised total entered". Note that the new values for the number of vehicles with L entries which would get away must not be less than the number turned back with no ensuing impact, as listed in Table 4-32. To do so would imply that the probability of getting away was so low that even the vehicles which actually got away would not have. Minimum values of P are given by one minus the ratio of number of "no impact in zone" divided by the total number of L side entries, both given in Table 4-32.

The data for this analysis are simply the speeds for first impacts in the first departure as a function of lateral distance from the road. These data are given in Table 4-35. (Impact speed was known for 6,291 first impacts; of these, 6,130 occurred at known lateral distances.)

TABLE 4-35 IMPACT SPEED FOR LATERAL DISTANCE TO IMPACT

(First Event)

Distance (ft.)	Frequency	Mean Impact Speed (MPH)
0-3	501	36.1
4-6	845	33.2
7-9	740	32.8
10-12	1,024	32.4
13-15	668	30.0
16-20	773	29.7
21-30	763	28.7
31-40	392	27.6
41-60	267	28.2
61-100	111	26.9
101+	46	28.6
TOTAL	6,130	31.2

There was an overall mean speed for first impacts of 31.2 MPH. Somewhat surprisingly, however, the reduction in speed as a function of distance from the road was not very large. Maximum speeds occurred in the 0-3 zone with a mean of 36.1 MPH; the minimum mean speed was 26.9 MPH in the 61-100 zone. The difference between the two is 9.2 MPH.

It is interesting to note that the means appear to bottom out beyond 30 feet. Indeed, the mean speeds were somewhat higher in the 41-60 zone and in the 101+ zone than they were in the immediately preceding zones. It was thought that perhaps this was due to higher speed vehicles on limited access roads. Because such roads tend to have more distal border areas and higher speed traffic, they might tend to have higher speed impacts further from the road. To examine this possibility, the analysis was repeated including only accidents on roads with no access control. While the overall mean speed was somewhat lower (30.8 MPH), the same bottoming out of impact speeds was present although it was not obvious until lateral distances exceeded 40 feet. Also present was the increase for the 101+ zone. This, then, offered no clarification.

Returning to the data in Table 4-35, it can be seen that there were only 46 observations in the last zone. Thus, this increase might be due to increased variability of the mean and discarded. However, considering that the bottoming out began to occur well before the last zone, it is likely that it reflects real-world effects.

As a final note in this regard, one might think to argue that higher speed vehicles travel further, but the truth of this is not sufficient for the truth of the converse. Higher speed vehicles can be expected to lose speed as they penetrate deeper into the roadside, and should, therefore, contribute to speed reductions with lateral distance just as do lower speed vehicles.

Going on to simulate the expected effects of a clear zone (of width H), it was only necessary to recompute the mean speeds using those vehicles whose first impact occurred beyond H. That is, if H=3, then all impacts would have occurred beyond three feet; their mean would be given by the mean of the speeds for all first impacts beyond three feet. The results of such calculations is given in Table 4-36.

TABLE 4-36 EXPECTED FIRST IMPACT SPEED FOR WIDTHS OF HYPOTHETICAL CLEAR ZONES

Clear Zone Width (ft.)	Expected Mean Speed (MPH)	Based on Frequency of:	Energy Reduction (%)
As is	31.2	6,130	-
3	30.7	5,629	3.2
6	30.3	4,784	5.7
9	29.9	4,044	8.2
12	29.0	3,020	13.6
15	28.7	2,352	15.4
20	28.2	1,579	18.3
30	27.8	816	20.6
40	27.9	424	20.0
60	27.4	157	22.9
100	28.6	46	16.0

As might have been expected from the small reductions in speeds for all first impacts, the results show the effects of clear zones to be limited. The minimum mean impact speed would have been 27.4 MPH; this is only a 3.8 MPH reduction from the actual situation without clear zones.

It should be noted, however, inasmuch as severity is more closely related to energy than speed, it is appropriate to consider the differences in squared speed. With this in mind, the percent energy reduction was calculated and listed in Table 4-36. For example, for a clear zone of nine feet, the reduction was calculated as $(31.2^2 - 29.9^2) \div 31.2^2 = .082$.

While one cannot directly relate these values to severity because of the incomplete knowledge pertaining to severity versus energy relationships, as well as the effects of other variables (vehicle mass, object type, impact type, etc.), it is reasonable to assume that on the average, the greater the energy reduction, the greater the severity reduction. On this basis, if we consider a benefit to cost ratio as measured by percent energy reduction divided by clear zone width, the values lie between 0.9%/ft. and 1.1%/ft. for clear zones up to 20 feet. Beyond that, the bottoming out of speed reductions shown in Table 4-35 takes effect, and the ratios drop off to 0.7, 0.5, 0.4, and 0.2%/ft. for the last four zones respectively. On this basis, then, diminishing returns set in beyond 20 feet.

As a final analysis in this section, mean speeds for the first impact were tabulated as a function of border offset. The previous analysis presented a view of hypothetical clear zone effects on impact speed. The current analysis differs in that (1) the first impact may have occurred before the border was reached, and (2) it contains no hypothetical components. The results are in Table 4-37.

The results in Tables 4-36 and 4-37 are basically similar. Both show an initial reduction in impact speeds. The clear zone results suggest minimum speeds for 30 to 60 foot offsets; the border results show a minimum in the 11 to 40 foot range. This is to be expected in that the clear zone analysis precluded impacts before the edge of the zone, whereas, earlier results had shown that 40 percent of all first impacts occurred before the border (with only 14 percent beyond it). Thus, an increase in border offset need not induce a commensurate increase in lateral distance to the first impact.

TABLE 4-37 IMPACT SPEED FOR BORDER OFFSET

(First Event)

Border Offset	N	Mean Impact Speed (MPH)
0 - 10	787	31.6
11 - 20	748	28.7
21 - 30	391	30.3
31 - 40	211	29.3
41 - 60	194	31.3
61 - 100	103	32.4
101 - 300	40	36.1
301 +	332	34.2

Finally, the results in Table 4-37 clearly show an increase in mean impact speed for border offsets exceeding 40 feet.

In order to attempt some clarification of this effect, an additional analysis was performed. It seemed plausible that large border offsets were conducive to high travel speeds due to (1) a positive correlation between road quality and border offset and/or (2) direct border offset effects (for example, reduced driver-perceived "friction" with the roadside and improved sight distance at curves). Because the data did not contain reliably reported travel speed, this could not be examined directly. As an alternative, a regression analysis was performed with impact speed as the dependent variable and border

offset and lateral distance to the first impact as the independent variables. Based on these results, a part correlation coefficient was computed for impact speed and border offset with the effects of lateral distance on impact speed removed.*

The results gave a coefficient of determination of 0.29 (R = 0.54) with beta coefficients of 0.38 for border offset and -0.45 for lateral distance. This shows that impact speed increased with border offset and decreased with lateral distance, with the latter having the somewhat greater effect. Next, the coefficient of part correlation between impact speed and border offset with the effects of lateral distance on impact speed removed was calculated; the value was 0.43.

Since the distance traveled is the primary source of speed reduction from the road to first impact, these results suggest that the increase in impact speed for larger border offset was indeed due to higher travel speeds.

In summary, the impact speed analysis suggests real, but limited benefits regarding impact speed for clear zones up to 20 or perhaps 30 feet. Beyond that, little benefit would be expected. The data, taken at face value, suggest that very large clear zones may be countereffective. The implication that large offsets are conducive to higher travel speeds, suggests the potential benefit of large offsets would not be realized unless coupled with the control of travel speeds.

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* Literal interpretation of these results must take into account the methods of the analysis. First, the analysis was based on mean impact speeds within border offset by lateral distance cells; while the means were weighted by the number of observations, random variation within cells was not included. Second, the regression was linear in order to determine first order effects. Thus, not only was the initial multiple regression linear in nature, but the adjustment for lateral distance effects involved only the removal of the linear component.

4.4 Summary of Findings for Off-Road Factors

1. Most of the accidents had basically simple configurations. Almost one-half involved one departure and one event. Twenty-four percent involved two events in a single phase and fourteen percent had two events in two phases. These three groups accounted for 85 percent of the accidents.

2. Of all events, 31 percent were rollovers, 56 percent were non-rollover impacts, and thirteen percent were nonimpact departures. Of all accidents, 48 percent involved at least one rollover.

In the following, references to the incidence of event types (rollovers, nonrollover impacts, and nonimpact departures) are always intended to reflect their proportion among all three types of events. Thus, a decrease in one event type is conducive to corresponding increases in the other two. Where possible, emphasis is placed upon the type believed to be the instrumental one.

3. As a proportion of all event types, the incidence of rollovers was highest in the second phase. This was due to the propensity for rollovers to be the last event in an accident and the high proportion of multideparture accidents which had two phases.

4. Both departure angle and departure attitude directly influenced nonimpact departures. Shallow angles and tracking vehicles were conducive to departures without impacts. Rollovers were more frequent for nontracking, versus tracking, vehicles. While rollovers were more frequent when departure angles were large, this was a reflection of the reduction in nonimpact departures and the correlation between departure angle and departure attitude.

5. Utility vehicles and heavy trucks without trailers had the highest rollover rates; automobiles had the lowest. Among cars, the rollover rate decreased with increasing size.

6. No systematic relationships were found between shoulder width (including no shoulder) and event type.

7. (a) Rollovers constituted a larger proportion of the events for roads built on fill as compared to ditch cut roads. Ditch cut roads would have had more nonimpact departures but for their higher incidence of nonroll impacts with ditches, embankments, and culverts.

   (b) Increased height of fill and depth of ditches were conducive to rollovers. Rollover rates began to increase when fill exceeded two feet and reached a plateau for fill greater than, or equal to, four feet. Rollover rates jumped markedly for ditches four to five feet deep. Beyond that, rollovers decreased as nonroll impacts with ditches increased.

   (c) As the slope of fill and ditches increased, the proportion of nonimpact departures decreased. The effect was observed for slopes greater than 4:1 for fill and 3:1 for ditches.

8. (a) The likelihood of hitting a wooden utility pole decreased five percent for each six feet of increased offset.

   (b) Impact speed decreased moderately with pole offset, but only when offset exceeded 24 feet.

9. (a) Median lateral distances were 10 to 12 feet for first impacts, 13 to 15 feet for all impacts, and 21 to 30 feet for final rest. The median of the maximum lateral distances were 16 to 20 feet for the first departure and 21 to 30 feet overall. For nonimpact first departures, maximum lateral distance had its median in the 4 to 6 foot range.

(b) In the first phase, 47 percent of the second impacts occurred beyond the first impact, six percent were between the road and the first impact, and 47 percent were approximately equidistant from the road.

(c) Thirty-nine percent of the first events occurred between the road and the border; 47 percent occurred near the border. As the border offset increased, so did the maximum lateral distance.

(d) The proportion of nonrollover impacts was maximum among impacts occurring at the border, rather than those between the road and the border, or those beyond the border.

10. (a) For hypothetical clear zones, the increase in the proportion of vehicles getting away in the first phase, was estimated to be near 0.4 percent per foot of clear zone width for widths from six to sixty feet.

(b) Impact speeds were estimated to have decreased very gradually as clear zone width increased. The associated reduction in kinetic energy was estimated to be 23 percent for clear zones of 60 feet. Decreases in impact speeds were clearly associated with increased (actual) border offsets only up to twenty feet.

(c) Large border offsets appeared to be conducive to a counter-productive increase in travel speeds.

11. In the study of off-road factors, the effects of greatest magnitude were:

(a) the effect of departure angle on nonimpact departures

(b) the effect of departure attitude on nonimpact departures and rollovers

(c) the effect of vehicle type on rollovers

(d) the effect of fill height and ditch depth on rollovers

(e) the effect of ditch and fill slope on nonimpact departures

(f) the effect of pole offset on pole impacts

(g) the effect of borders on nonroll impacts.

Also notable were:

(h) undetected effects of shoulder width on event type

(i) small reductions in impact speeds with lateral distance, offsets, and hypothetical clear zone width

(j) small increases in the likelihood of a nonimpact departure for hypothetical clear zones.

5. IMPACT CHARACTERISTICS

This section is devoted to the description of impacts in single vehicle accidents. The major impact factors discussed are impact behavior, impact speed, object struck, and area of damage. They gain their importance, as will be seen in Section 6, from their influence on injury.

5.1 Primary Impacts

One basic concern in planning the injury analyses was the fact that, generally speaking, injury could not be associated with any particular impact. Thus, for example, in assessing the effects of impact speed on injury, which impact should be used? One approach was to utilize the subset of accidents which had only one impact. This, however, had two major disadvantages. First, results would apply only to single impact accidents. Second, the number of observations would be diminished.

The approach which was ultimately selected was that of using the primary impact. While other impacts in a multi-impact accident undoubtedly contributed to injury at times, it was thought that the injury was most likely to occur as a result of primary impact, and, conversely, the primary impact is the one which best reflects threat to injury. It should be noted that when comparable analyses were conducted using primary impacts and single impacts, little difference between the two was typically observed.

The primary impact, for any accident, was that impact which was thought to be the most severe one. Generally this was interpreted to mean the impact with the highest change in velocity (ΔV), but accidents in which rollover and non-rollover impacts occurred, the coder was required to use his best judgment, since the respective ΔV's were estimated over different time intervals. There could be no more than one primary impact per accident. All of the following analyses were based on the primary impact unless otherwise noted.

Table 5-1 shows where the primary impact occurred relative to other impacts in the accident sequence. The righthand column shows that almost three-fourths of the primary impacts were first impacts; 95 percent of the primaries were first or second impacts.

TABLE 5-1 LOCATION OF THE PRIMARY IMPACT WITHIN THE ACCIDENT SEQUENCE

Impact Number	Number of Impacts* 1 N	%	2 N	%	3 N	%	4 N	%	Total N	%
1	4,922	100.0	663	28.9	52	9.6	7	6.8	5,644	71.8
2			1,628	71.1	177	32.8	9	8.7	1,814	23.1
3					311	57.6	38	36.9	349	4.4
4							49	47.6	49	0.6
TOTAL	4,922	100.0	2,291	100.0	540	100.0	103	100.0	7,856	100.0

*One five impact accident was omitted from the table; for it, the primary impact was the last one.

Looking at the individual columns, which group accidents by the number of impacts, it can be seen, in apparent contrast to the result above, that the primary impacts occurred most often as the last impact in the sequence. For example, there were 540 accidents involving three impacts; thus, there were 540 first impacts, 540 second impacts, and 540 third impacts. Of the first impacts, ten percent were primary; of the second impacts, one-third were primary; and of the last impacts, over one-half were primary. Thus, as was shown earlier for rollovers, there was a tendency for vehicles to continue until a primary impact occurred.

That most primaries were first impacts on an overall basis, but last impacts when accidents were grouped by impact frequency is quite reasonable. Suppose the ΔV's were very low for nonprimary impacts and very high for primary impacts, so that all vehicles would continue until a primary occurred and then would stop. Then all primaries would be last impacts and all last impacts would be primary. The overall result would be that the number of primary

first impacts would equal the number of single impact accidents, the number of primary second impacts would equal the number of two impact accidents, etc. Also, consider that most accidents had one impact, fewer had two, still fewer had three, etc. Thus, on an overall basis, most primaries would be first impacts, fewer would be second impacts, etc., even though all primaries would have been last impacts.

5.2 Impact Behavior

Event type had been discussed extensively in previous analyses. This three-valued variable was based on a more detailed variable reflecting impact behaviors plus a nonimpact code. The distribution of primary impact behaviors is given in Table 5-2.

TABLE 5-2 IMPACT BEHAVIOR - PRIMARY IMPACTS

Behavior	All Events N	All Events %	Within Groups %
Nonrollover Impact:			
Continue	2,073	26.1	48.1
Stop	1,543	19.4	35.8
Thru or Over	312	3.9	7.2
Redirect to Road	336	4.2	7.8
Vault	33	0.4	0.8
Other, Unknown	16	0.2	0.4
	4,313	54.3	100.0
Rollover Only:			
Less than One Complete Roll	1,817	22.9	54.1
One Roll	903	11.4	26.9
More than One Roll	639	8.1	19.0
	3,359	42.3	100.0
Compound Rollover:			
Continue	151	1.9	57.0
Stop	99	1.2	37.4
Thru or Over	7	0.1	2.6
Redirect to Road	3	0.0	1.1
Vault	4	0.1	1.5
Other, Unknown	1	0.0	0.4
	265	3.3	100.0
TOTAL	7,937	100.0	100.0

The results show that just over half of the primary impacts were nonrollovers, 42 percent were "pure" rollovers, and three percent were compound rollovers (i.e., the vehicle struck an object during a rollover).

When considering only nonrollover impacts, almost one-half were followed by continued travel of the vehicle either to another event or to final rest. The vehicles stopped, essentially immediately, after approximately one-third of the impacts. Other, less frequent, vehicle behaviors included traveling over or through the object struck (e.g., through a clump of small trees), a path deflection taking the vehicle back to the road, and vaulting (e.g., over a large rock). A similar ordering of frequencies was observed for vehicle behaviors involving simultaneous rollover and collision.

For those events involving "pure" rollovers, 27 percent had one full rollover (i.e., a complete 360 degrees), 54 percent had less than one complete roll, and 19 percent had a more extended rollover. Note that a rollover reflects one continuous event; when a vehicle experienced several separate rollovers, each was recorded as a single event.

Overall, the data show the most frequent primary impact behavior was a pure rollover. Next were a nonroll impact with continued travel, and a nonroll impact and stop. These three events accounted for 88 percent of all primary impacts.

5.3 Impact Speed

Another variable that is useful in describing the characteristics of single vehicle impact is the impact speed; its distribution is given in Table 5-3.

TABLE 5-3 SPEED OF PRIMARY IMPACTS

Impact Speed (MPH)	Primary Impacts N	%
0-10	683	8.9
11-20	1,861	24.2
21-30	2,731	35.6
31-40	1,429	18.6
41-50	679	8.8
51-60	219	2.9
61-98	79	1.0
Unknown	256	-
TOTAL	7,937	100.0

Almost 80 percent of the primary impact speeds were in the 11 to 40 MPH range. The most frequently appearing range was 21 to 30 MPH. Table 5-4 gives impact speeds for each of the three major groupings of primary impact behaviors.

TABLE 5-4 IMPACT SPEED BY PRINCIPAL IMPACT BEHAVIOR

	Rollovers		Compound Rollovers		Non-Roll Impacts	
Speed (MPH)	N	Cum.%	N	Cum.%	N	Cum.%
0-10	35	1.0	19	7.9	629	15.3
11-20	537	17.1	60	32.8	1,264	46.2
21-30	1,646	66.4	71	62.2	1,014	70.9
31-40	775	89.6	51	83.4	603	85.7
41-50	293	98.3	21	92.1	365	94.6
51-60	44	99.6	13	97.5	162	98.5
61+	12	100.0	6	100.0	61	100.0
Unknown	17	-	24	-	215	-
TOTAL	3,359		265		4,313	

The proportion of lower speed impacts (20 MPH or less) varied considerably among the three impact types. They constituted one-sixth of the pure rollovers, one-third of the compound rollovers, and almost one-half of the nonrollovers. Thus, on the average, rollovers occurred at higher speeds than did nonrollovers.

5.4 Object Struck

Table 5-5 gives the distribution of objects struck for nonrollover impacts. It includes all such impacts and, separately, primary nonrollover impacts. Considering either data set, the most frequent grouping of objects was terrain, followed by natural objects, posts and poles, and fixed objects. Permanent barriers and road structures had still lower frequencies, and temporary objects and attenuators were struck very infrequently. In noting the relative infrequency of temporary objects, it is important to bear in mind that the sample was designed to specifically exclude accidents involving collisions prior to departure; one might expect a higher representation of these objects if the sample were not restricted in this way.

Regarding individual objects struck in nonroll impacts, the ten most frequent, in descending order, were trees, fences, wooden utility poles, embankments, ditches, guardrails, culverts, trees and brush (this includes clumps of small trees), ground, and field approaches. Together, these ten objects accounted for three-fourths of all objects struck in nonrollover impacts.

The comparison of all impacts and primary impacts provides some initial information pertaining to severity. To facilitate this comparison, refer to the last tabular column. It shows, for example, that 17 percent of the curb impacts were primary while 58 percent of the ditch impacts were primary; this suggests that curb impacts were less severe than ditch impacts. At the bottom of the table, it is shown that 57 percent of all nonrollover impacts were primary; thus, the 17 percent for curbs was unusually low.

TABLE 5-5 OBJECT STRUCK - NONROLLOVER IMPACTS

	All Impacts		Primary Impacts		%
	N	%	N	%	Primary
Terrain					
Curb	35	0.5	6	0.1	17.1
Ditch	642	8.5	374	8.7	58.3
Embankment	773	10.3	413	9.6	53.4
Road Fill	2	0.0	0	0.0	0.0
Field Approach (Raised Driveway)	220	2.9	75	1.7	34.1
Culvert	436	5.8	239	5.5	54.8
Snowbank	38	0.5	8	0.2	21.1
River, Pond, Etc.	51	0.7	24	0.6	47.1
Ground	224	3.0	156	3.6	69.6
Other, Unknown	108	1.4	14	0.3	13.0
	2,529	33.6	1,309	30.4	51.8
Posts, Poles					
Small Sign Post	191	2.5	76	1.8	39.8
Traffic Signal Post	0	0.0	0	0.0	-
Wooden Utility Pole	782	10.4	620	14.4	79.3
Other Wooden Pole	39	0.5	28	0.6	71.8
Metal Sign Support - B*	14	0.2	9	0.2	64.3
Metal Sign Support - NB**	19	0.3	11	0.3	57.9
Metal Sign Support - Unk.	24	0.3	12	0.3	50.0
Metal Other - B	2	0.0	1	0.0	50.0
Metal Other - NB	12	0.2	11	0.3	91.7
Metal Other - Unk.	6	0.1	4	0.1	66.7
Concrete Base - Sign	4	0.1	2	0.0	50.0
Concrete Base - Other	2	0.0	1	0.0	50.0
Delineator	147	2.0	19	0.4	12.9
Other, Unknown	25	0.3	11	0.3	44.0
	1,267	16.9	805	18.7	63.5
Natural Objects					
Tree	874	11.6	674	15.6	77.1
Trees, Brush	386	5.1	266	6.2	68.9
Rock(s)	135	1.8	75	1.7	55.6
Other, Unknown	17	0.2	7	0.2	41.2
	1,412	18.8	1,022	23.7	72.4

* B = Breakaway
**NB = Nonbreakaway

TABLE 5-5 (CONTINUED)

	All Impacts		Primary Impacts		% Primary
Fixed Objects	N	%	N	%	
Fence	835	11.1	331	7.7	39.6
Mailbox	172	2.3	32	0.7	18.6
Hydrant	3	0.0	2	0.0	66.7
Junction Box	14	0.2	4	0.1	28.6
Building	45	0.6	34	0.8	75.6
Other, Unknown	141	1.9	77	1.8	54.6
	1,210	16.1	480	11.1	39.7
Temporary Objects					
Traffic Cones	0	0.0	0	0.0	-
Traffic Barrels	6	0.1	3	0.1	50.0
Construction Barriers	4	0.1	2	0.0	50.0
Construction or Other Equipment	5	0.1	3	0.1	60.0
Construction Excavation	1	0.0	1	0.0	100.0
Other, Unknown	6	0.1	2	0.0	33.0
	22	0.3	11	0.3	50.0
Permanent Barriers					
Guardrail	505	6.7	286	6.6	56.6
Concrete Barrier	5	0.1	4	0.1	80.0
Guard Post(s) - Wood	37	0.5	17	0.4	45.9
Guard Post(s) - Concrete	8	0.1	5	0.1	62.5
Guard Post(s) - Other, Unknown	15	0.2	4	0.1	26.7
	570	7.6	316	7.3	55.4
Attenuators					
Fibco	1	0.0	1	0.0	100.0
Other, Unknown	1	0.0	1	0.0	100.0
	2	0.0	2	0.0	100.0

TABLE 5-5 (CONTINUED)

Road Structures	All Impacts N	All Impacts %	Primary Impacts N	Primary Impacts %	% Primary
Tunnel - Internal Wall	3	0.0	1	0.0	33.3
Underpass:					
Internal Wall	1	0.0	0	0.0	0.0
Internal Support	8	0.1	5	0.1	62.5
Entrance	3	0.0	3	0.1	100.0
Other, Unknown	0	0.0	0	0.0	-
Bridge/Overpass:					
Side Rail	143	1.9	87	2.0	60.8
Entrance	115	1.5	88	2.0	76.5
Other, Unknown	4	0.1	3	0.1	75.0
Retaining Wall	11	0.1	9	0.2	81.8
Other, Unknown	0	0.0	0	0.0	-
	288	3.8	196	4.5	68.1
Other, Unknown	217	2.9	172	4.0	79.3
TOTAL	7,517	100.0	4,313	100.0	57.4

Considering only those objects which were struck at least 100 times, the highest proportions of primaries were for wooden utility poles, trees, bridge/overpass entrances, ground, and trees and brush. With the same restriction, the smallest proportions of primaries were for delineators, mailboxes, field approaches, small sign posts, and fences. In general, it appears that the proportion of primaries was high for those objects likely to stop the vehicle upon contact.

The previous table excluded rollovers in order to emphasize "normal" impacts. Table 5-6 includes all primary impacts. As one can see from the first column, in 3,342 of the 3,359 accidents (or 99.5%) in which rollover was the primary impact, the object contacted was ground. This reflects the practice adopted, whereby the object contacted during a rollover was almost exclusively coded "Ground". Considering the remaining sixteen rollover accidents in which the object contacted was not "Ground", note that five of them were coded "Ditch" and another "Embankment", both of which are actually refinements of the "Ground" code; the rest appear to be coding or keypunching errors.

Ground contacts coded for compound rollovers (3.3% of all ground contacts) may be slightly misleading; they are a special code signifying the end of an event such as a vault. Ground contacts in nonrollover primary impacts were coded for bona fide vehicle contact with the ground, e.g., undercarriage contacts.

TABLE 5-6 VEHICLE BEHAVIOR BY OBJECT CONTACTED

(Primary Impacts)

Object	Rollover		Compound Rollover		No Rollover		Total	
	N	%	N	%	N	%	N	%
Ground	3,342	92.4	119	3.3	156	4.3	3,617	100.0
Tree	1	0.1	34	4.8	674	95.1	709	100.0
Wooden Utility Pole	0	0.0	24	3.7	620	96.3	644	100.0
Ditch	5	1.3	8	2.1	374	96.6	387	100.0
Embankment	1	0.2	21	4.8	413	94.9	435	100.0
Fence	1	0.3	6	1.8	331	97.9	338	100.0
Guardrail	0	0.0	8	2.7	286	97.3	294	100.0
Culvert	0	0.0	5	2.0	239	98.0	244	100.0
Trees, Brush	0	0.0	15	5.3	266	94.7	281	100.0
Field Approach	0	0.0	1	1.3	75	98.7	76	100.0
Other	9	1.0	24	2.6	879	96.4	912	100.0
TOTAL	3,359	42.3	265	3.3	4,313	54.3	7,937	100.0

A property of the roadside environment that is relevant to defining the single vehicle accident problem is the location of the various objects with respect to the road edge*. Only the lateral distances from the roadside are examined; unlike the longitudinal and trajectory distances, the offset is independent of the point from which the vehicle departed the roadway. Table 5-7 gives the lateral distance for each object struck more than 50 times.

The objects struck which were closest to the road were bridge and overpass structures, guardrails, and small sign posts; those farthest from the road were trees and brush, single trees, fences, and ground. Some objects might appear to be surprisingly far from the road; for example, wooden utility poles over 60 feet away or guardrails over 40 feet away. This is due to the fact that some of these objects were near other roads which intersected the departure road.

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* An earlier analysis presented offsets for various border types. The data given here differ in that (1) the object was struck not just present, and (2) the object need not have constituted part of a (nontraversable) border.

TABLE 5-7 LATERAL DISTANCES TO SELECTED OBJECTS STRUCK IN PRIMARY NONROLLOVER IMPACTS

	Lateral Distance (Ft.)											
	0-6		7-12		13-20		21-40		41-60		61+	
Object	N	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%	N	Cum.%
Ditch	36	9.8	97	36.0	110	65.9*	86	89.2	20	94.6	20	100.0
Embankment	74	18.0	120	47.2	107	73.2*	88	94.6	11	97.3	11	100.0
Field Approach	5	6.8	17	30.1	28	68.5*	21	97.3	2	100.0	0	100.0
Culvert	35	14.9	86	51.5*	61	77.4	41	94.9	6	97.4	6	100.0
Ground	17	11.8	25	29.2	37	54.9*	38	81.3	10	88.2	17	100.0
Small Sign Post	27	36.0	28	73.3*	13	90.7	6	98.7	1	100.0	0	100.0
Wooden Utility Pole	110	17.7	228	54.5*	152	79.0	105	96.0	17	98.7	8	100.0
Tree	55	8.2	121	26.2	176	52.4*	203	82.6	76	93.9	41	100.0
Trees, Brush	13	5.0	42	21.1	73	49.0	84	81.2*	31	93.1	18	100.0
Rock(s)	21	28.4	19	54.1*	19	79.7	10	93.2	5	100.0	0	100.0
Fence	18	5.6	73	28.2	84	54.2*	97	84.2	31	93.8	21	100.0
Guardrail	105	38.3	98	74.1*	45	90.5	20	97.8	3	98.9	3	100.0
B/O** - Side Rail	73	88.0*	8	97.6	2	100.0	0	100.0	0	100.0	0	100.0
B/O** - Entrance	78	88.6*	9	98.9	1	100.0	0	100.0	0	100.0	0	100.0

*Median

**Bridge or Overpass

5.5 Area of Damage

Of those accidents not involving rollover, approximately 60 percent of the primary impacts were frontal in nature. The results are presented in Table 5-8.

TABLE 5-8 DISTRIBUTIONS OF AREA OF DAMAGE - NONROLLOVER PRIMARY IMPACTS

Area of Damage	N	%
Front	2,530	59.7
Right	650	15.3
Back	117	2.8
Left	495	11.7
Top	32	0.8
Undercarriage	414	9.8
Unknown	75	--
TOTAL	4,313	100.0

This table also shows that in side impacts, the right side was more often damaged. Not surprisingly, the rear of the vehicle was seldom damaged in nonrollover accidents.

Closely related to area of damage is the direction of force at impact. Table 5-9 shows the frequency distribution of the direction of force for nonrollover accidents; again, the preponderance of frontal impacts is obvious.

The relationship between the direction of force and the general area of damage is illustrated in Table 5-10. As would be expected, most frontal impacts involved a 12 o'clock direction of force; some 12 o'clock impacts were sideswipes.

TABLE 5-9 PRINCIPAL DIRECTION OF FORCE FOR NONROLLOVER PRIMARY IMPACTS

Clock Direction of Principal Force	Primary Impacts N	Primary Impacts %
01	382	9.3
02	123	3.0
03	134	3.2
04	28	0.7
05	44	1.1
06	80	1.9
07	43	1.0
08	38	0.9
09	84	2.0
10	117	2.8
11	231	5.6
12	2,350	57.0
00 *	470	11.4
Unknown	189	--
TOTAL	4,313	100.0

* Nonhorizontal direction of force

TABLE 5-10 AREA OF DAMAGE AND PRINCIPAL DIRECTION OF FORCE FOR PRIMARY NONROLLOVER IMPACTS

Area of Damage	Clock Direction of Principal Force												
	01	02	03	04	05	06	07	08	09	10	11	12	Total
Front	104	33							1	29	77	2,258	2,502
Right	264	87	132	25	31	2	1*	2*		1*	1*	51	597
Back				2	12	78	6	6		1*			105
Left	14*	3*	2*	1*	1*		36	30	83	86	153	27	436
Top												4	4
Undercarriage												7	7
TOTAL	382	123	134	28	44	80	43	38	84	117	231	2,347	3,651

*Indicates probable coding error

5.5.1 Effects of Departure Characteristics on Area of Damage

Because area of damage in single vehicle nonrollover impacts is primarily determined by directional properties of the vehicle's motion, and because the available measures of departure behaviors referred to the directional properties of the departure, some additional analyses were conducted to relate departure characteristics to area of damage. It had previously been shown that departure attitude and angle had important effects on event type. In an effort to determine the factors contributing to the occurrence of nonfrontal, nonrollover accidents, the area of damage was analyzed as a function of the departure attitude (tracking/non-tracking), departure angle, and departure point. In order to concentrate on departure effects, these tables contain only those nonrollover impacts which were the first event in the first phase.

The results from Table 5-11 show that the likelihood of side and rear impacts was higher for vehicles which were not tracking when they left the roadway. The proportion of undercarriage and top contacts remained relatively constant regardless of departure attitude. Thus, the proportion of side and rear impacts increased an amount equivalent to the decrease in the proportion of frontal impacts.

TABLE 5-11 AREA OF DAMAGE BY DEPARTURE ATTITUDE - FIRST EVENT, NONROLLOVERS

	Tracking		Not Tracking	
Area of Damage	N	%	N	%
Front	2,022	70.0	593	48.5
Right	343	11.9	237	19.4
Back	23	0.8	54	4.4
Left	183	6.3	223	18.2
Top	11	0.4	1	0.1
Undercarriage	308	10.7	115	9.4
TOTAL	2,890	100.0	1,223	100.0

Table 5-12 gives the joint effects of departure attitude and departure angle on area of damage. In order to simplify this analysis, only frontal and nonfrontal impacts were compared. The righthand portion of the table shows the effects of departure angle irrespective of the attitude at departure. Ignoring the very large angles due to their inclusion of intersection-type accidents noted earlier, the data suggest a mild decrease in frontal impacts with increasing departure angle, but the effect was weak and not very orderly.

Looking at the main body of the table, it can be seen that for tracking and nontracking vehicles, taken separately, there is still no order to be found in the relationship between angle of departure and area of damage. In contrast, for each departure angle grouping, the proportion of frontal impacts was higher for the tracking vehicles - typically, in the neighborhood of 20 percent higher.

Thus, with regard to frontal versus nonfrontal impacts, departure angle had clear systematic effects only for those vehicles departing the road at angles of at least thirty degrees. In contrast, departure attitude had profound effects irrespective of the departure angle.

Finally, while the increase in frontal impacts for very large departure angles was, in part, attributable to "T" and "Y" intersections, there is another potential factor to consider. The results may suggest that when vehicles depart the road (not at intersections) at very large angles, at least partial control is regained off the road. Some support for this hypothesis can be gained from Reference 6 in the Literature Review in which it was suggested that large angle departures were related to lower departure speeds. This is consistent with regaining control at high departure angles, since the vehicle would have been traveling slower and thus the driver would have had more time to correct the vehicle. Further support might be obtained by examining the

TABLE 5-12 AREA OF DAMAGE BY DEPARTURE ANGLE AND DEPARTURE ATTITUDE FOR FIRST EVENT NONROLLOVERS

Angle (Degrees)	Area of Damage:	Departure Attitude						Overall*		
		Tracking			Not Tracking					
		Front	Not Front	% Front	Front	Not Front	% Front	Front	Not Front	% Front
0-2		74	34	68.5	6	5	54.5	87	41	68.0
3-5		213	113	65.3	10	16	38.5	254	145	63.7
6-8		376	177	68.0	44	41	51.8	485	247	66.3
6-11		308	119	72.1	66	91	42.0	424	251	62.8
12-14		119	59	66.9	45	47	48.9	199	119	62.6
15-20		248	107	69.9	94	87	51.9	409	224	64.6
21-29		143	61	70.1	92	94	49.5	286	190	60.1
30-45		134	38	77.9	81	53	60.4	257	110	70.0
46-79		48	16	75.0	45	29	60.8	113	55	67.3
80-90		69	10	87.3	16	9	64.0	88	20	81.5
Overall*		2,022	868	70.0	593	630	48.5			

*The overall frequencies are greater than the corresponding sums due to inclusion of unknowns. For example, the overall frequencies for tracking vehicles are not restricted to vehicles with known departure angles.

travel speed variable; however, only a police estimate of travel speed was available. In addition to having a large proportion of unknowns (99% in some states), many of the rest were based entirely on the statements of the drivers, thus making reported travel speed a relatively unreliable variable.

The departure point also affected the area in which the vehicle sustained damage; the data are given in Table 5-13. There was little difference in the proportion of frontal impacts in left and right side departures; however, note the reversal in relative frequency of left and right impacts: left side impacts were more prevalent in accidents in which the vehicle departed the roadway on the left and right side departures produced more right side impacts. Departures onto medians, in contrast with other left side departures, resulted in fewer frontal, but more left side and undercarriage impacts. Frontal impacts were overrepresented at "T", "Y", and jogged intersections.

TABLE 5-13 AREA OF DAMAGE BY DEPARTURE POINT FOR FIRST EVENT NONROLLOVERS

	Departure Point							
	Right Side		Left Side		Median		Intersection Type	
Area	N	%	N	%	N	%	N	%
Front	1,830	63.7	1,080	64.7	80	44.2	117	77.5
Right	507	17.6	144	8.6	19	10.5	10	6.6
Back	42	1.5	39	2.3	5	2.8	1	0.7
Left	196	6.8	240	14.4	46	25.4	8	5.3
Top	7	0.2	5	0.3	0	0.0	0	0.0
Undercarriage	293	10.2	160	9.6	31	17.1	15	9.9
TOTAL	2,875	100.0	1,668	100.0	181	100.0	151	100.0

5.6 Summary of Impact Characteristics

1. As with rollovers, off-road vehicles tended to continue until a primary impact occurred. On the other hand, because there were few accidents with many impacts, 72 percent of the primaries were first impacts, and 95 percent were first or second impacts.

2. Forty-two percent of the primary impacts were pure rollovers; another three percent were compound rollovers. One-quarter of the primary impacts were nonrollovers with continued travel, and one-fifth were nonrollovers with an immediate stop.

3. Approximately 80 percent of the primary impact speeds were between 11 and 40 MPH, with the modal range being 21 to 30 MPH. Impact speeds for pure rollovers were greater than those for nonrollover impacts; compound rollovers tended to have intermediate speeds.

4. The most frequent objects struck in nonrollover impacts were, in order of decreasing frequency, single trees, fences, wooden utility poles, embankments, ditches, guardrails, culverts, and trees and brush; each constituted at least five percent of the total. The proportion of impacts which were primary was highest for wooden utility poles, trees, bridge/overpass entrances, ground, and trees and brush; it was lowest for delineators, mailboxes, field approaches, small sign posts, and fences.

5. Overall, the most frequent object struck in primary impacts was the ground, but 95 percent of these impacts were rollovers. (Note that summary Item 4 refers to nonrollover impacts.)

6. Among the more frequently struck objects in nonrollover primary impacts, bridge/overpass structures were closest to the departure road and trees and brush, single trees, fences, and ground were the farthest.

7. Among primary nonrollover impacts, 60 percent involved frontal impacts. This figure was higher for tracking vehicles and lower for nontracking vehicles; changes in departure angles below 30 degrees had little effect on the proportion of frontal impacts.

8. Departures from the right side of the road were conducive to impacts to the right side of the vehicle; left side departures were conducive to left side impacts.

6. ACCIDENT SEVERITY

In the following, accident severity is described in terms of driver injury or, alternatively, in terms of the most severe injury to any occupant in the vehicle. Additional analyses were conducted on extent of vehicle damage. These were thought to be of lesser importance in that extent of damage is, for the purposes of this study, best viewed as a mediating factor (between impact characteristics and injury) over which the highway engineer has no direct control. As such, the extent of damage analyses appear in the Special Studies Section.

6.1 Background

6.1.1 Driver and Occupant Injury

Police-reported injury appeared in two separate variables: driver injury, and the most severe injury in the vehicle. The primary difference between these two variables is that because the most severe injury reflects all occupants (including the driver), it is a better measure of overall accident costs, but from a theoretical viewpoint, it is less desirable since it is dependent on the number of occupants in the vehicle.

Although the analysis of driver injury is likely to produce more precise statistics, it was decided to rely primarily on the most severe occupant injury because it provides a better summary of real-world effects. The upper part of Table 6-1 gives police-reported injury for the driver and then the most severe injury for all occupants.

An earlier study of the quality of police reported injury suggested such information could be misleading.* In that study, police-reported injury was compared to injuries rated on the Abbreviated Injury Scale (AIS) as determined from physicians' medical reports. Only occupants taken to a hospital were included. Using the standard police and AIS definitions, the

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*Garrett, J.W., Braisted, R.C., and Morris, D.F., "Tri-Level Accident Research Study: Final Report - Second Annual Report", Calspan Report No. VJ-2893-V-2, May 1972.

two injury scales were matched and agreement between the two was measured. Using 1,484 accident victims for which both police-reported injury and AIS were known, it was found that agreement existed for only 48 percent of the occupants. On the other hand, for the 44 fatalities, 42 were so reported by the police thereby giving a 95 percent agreement rate. Thus, while the police reporting of fatalities was relatively accurate, the reporting of nonfatal injuries was not.

As a result of these considerations, it was decided that the data would more appropriately reflect the facts if the A, B, and C police-reported injury levels were grouped together. Hence, injuries will be discussed on a simple three-point scale: no injury, nonfatal injury, and fatal injury. The data, so grouped, are shown in the lower portion of Table 6-1.

TABLE 6-1 DRIVER AND OCCUPANT INJURY

Police-Reported Injury	Driver		Severest Injury in Vehicle	
	N	%	N	%
None	3,741	47.8	3,369	43.0
C	707	9.0	696	8.9
B	1,593	20.4	1,644	21.0
A	1,497	19.1	1,739	22.2
Fatal	281	3.6	380	4.9
Total	7,819	100.0	7,828	100.0
Unknown	153		144	
Grand Total	7,972		7,972	
- A, B, and C Grouped -				
None	3,741	47.8	3,369	43.0
Nonfatal	3,797	48.6	4,079	52.1
Fatal	281	3.6	380	4.9
Total	7,819	100.0	7,828	100.0

The data show that over half of the drivers suffered an injury. Forty-nine percent had nonfatal injuries, and almost four percent had fatal injuries. When considering the severest injury in the vehicle, the values were somewhat higher. This simply reflects the greater opportunity for injury when all occupants are considered. In 52 percent of the vehicles, there was at least one injury but no fatalities. In five percent of the vehicles, there was at least one fatal injury.

6.1.2 Restraint Use and Ejection

The analysis of injury was not controlled for restraint usage. Desirable as this may have been, this variable was not universally reported by the cooperating police agencies. In fact, in almost one-third of the accidents, driver restraint use went unreported. The data set does, however, demonstrate the efficacy of restraint use. Table 6-2 relates injury to restraint use; the advantages are obvious.* For example, the percent of fatal injuries was four times higher for unrestrained drivers.

TABLE 6-2 DRIVER INJURY BY RESTRAINT USE

Restrained	Injury: None	Nonfatal	Fatal	Total	Injured: N	%	% Killed
Yes	419	269	8	696	277	39.8	1.1
No	2,031	2,397	203	4,631	2,600	56.1	4.4
Total	2,450	2,666	211	5,327			

*In this injury table, and those that follow, the first three columns represent mutually exclusive injury categories. On the other hand, the number and percent injured includes both fatal and nonfatal injuries.

Another variable having major effects on injury, but which was not universally reported, is ejection; its effect upon driver injury is shown in Table 6-3. Note that almost all ejected drivers were injured, that the injury rate was almost doubled for ejected drivers, and that the fatality rate increased more than ten-fold when ejections occurred.

TABLE 6-3 DRIVER INJURY BY EJECTION

Ejected	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Yes	17	325	130	472	455	96.4	27.5
No	1,776	1,921	85	3,782	2,006	53.0	2.2
Total	1,793	2,246	215	4,254			

One of the major advantages of using safety belts is their effect upon ejection. This is shown in Table 6-4 where the likelihood of ejection is more than five times higher for unrestrained drivers. (Presumably, the 13 restrained drivers who were ejected reflect either partial ejections, restraint failures, or inaccurate driver-provided information.)

TABLE 6-4 DRIVER EJECTION BY RESTRAINT USE

Ejected	Restrained: N	Restrained: %	Not Restrained: N	Not Restrained: %
Yes	13	2.2	381	12.1
No	575	97.8	2,770	87.9
Total	588	100.0	3,151	100.0

Further effort in analyzing restraint useage would obviously be hampered by the quantity of unreported data for the restraint use variable; however, regardless of any other findings, it should be clear that the use of available restraint systems is both an effective and inexpensive countermeasure in single vehicle accidents.

6.2 Most Severe Occupant Injury and Impact Characteristics

The following results reflect the most severe injury sustained by any occupant in the accident vehicle. All analyses were based on impact characteristics associated with the primary impact. There is some variation in the totals from table to table since unknowns associated with the independent variable were excluded for simplicity. The total number of accidents with an identifiable primary impact and most severe injury was 7,793.

6.2.1 Impact Behavior

Table 6-5 gives injury statistics as a function of impact behavior. When comparing impact types, the results show that rollovers had an 18 percent higher injury rate and a three percent higher fatality rate than did the nonroll impacts. Considering only rollovers, the injury and fatality rates increased with the extent of the roll; notice that the rates for compound rolls (impacts with objects during a rollover) and those for extended rolls (greater than 360°) were essentially equivalent and very high.

For the nonrollover impacts, the highest rates were associated with "other." This reflects the inclusion of vaulting in this category. However, the total number of observations was quite low; and these data were included only for completeness of the nonroll impact totals. The next most hazardous category was stopping at impact. While this group included some vehicles with very low impact speeds, the high injury and fatality rates were due to impacts with objects sufficiently substantial to stop the vehicle, thereby rendering a high ΔV.

TABLE 6-5 SEVEREST INJURY BY IMPACT BEHAVIOR

Behavior	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
Rollovers:							
Roll < 360°	791	956	48	1,795	1,004	55.9	2.7
Roll 360°	260	575	48	883	623	70.6	5.4
Roll > 360°	100	432	100	632	532	84.2	15.8
Compound Roll	38	171	39	248	210	84.7	15.7
All Rollovers	1,189	2,134	235	3,558	2,369	66.6	6.6
Nonroll Impacts:							
Stop	670	774	66	1,510	840	55.6	4.4
Thru and Over	228	74	5	307	79	25.7	1.6
Continue	1,248	1,038	69	2,355	1,107	47.0	2.9
Other	14	28	6	48	34	70.8	12.5
All Nonroll Impacts	2,160	1,914	146	4,220	2,060	48.8	3.5
Overall	3,349	4,048	381	7,778	4,429	56.9	4.9

$$X^2_{14} = 732.39 \text{ (S)}, \quad C = 0.29$$

The least hazardous impact behavior involved striking an object and then traveling through or over it. Examples include small trees and, as will be seen later, guardrails. In these impacts, the attendant speed reduction (ΔV) would be small so as to yield little threat of injury.

The remaining impact behavior category included those vehicles which struck an object and continued moving to final rest, to another impact, or back to the road. Here ΔV could be expected to have intermediate values. The injury and fatality rates were very close to the overall rates for all nonroll impacts.

Thus, rollovers were more hazardous than were the nonroll impacts; this was particularly true for extended and compound rolls. The least hazardous behavior was a through or over nonrollover impact.

While this discussion has emphasized injury and fatality rates as indices of hazard for the various impact behaviors, it is also useful to consider the magnitude of the problem associated with each behavior. This is best indexed simply by the number of injuries and fatalities associated with each. In this sense, rollovers were a greater problem than nonroll impacts; they yielded over half of the injuries and over 60 percent of the fatalities. Regarding specific behaviors, injury frequencies were highest for nonroll impacts with continued travel and rollovers less than 360°; the single category containing the most fatalities was the extended rollover.

Finally, it was desirable to quantify the influence of impact behavior on injury. The contingency coefficient was selected for this purpose.* Since it is based on the chi-square statistic, both are provided at the bottom of the table; chi-squared equalled 732.39 on 14 degrees of freedom which is statistically significant at the 0.05 level (denoted by S), and the contingency coefficient equalled 0.29. The contingency coefficient, while not a perfect measure of correlation, has a minimum value of zero and increases with increasing association of the two variables, but never reaches the value of one. Its major reason for inclusion was to provide a guide for comparing the strength of the influence on injury among the factors studied.

6.2.2 Impact Speed

The effect of speed of the primary impact upon injury is given in Table 6-6. It is quite apparent that both the injury rate and the fatality rate increased with impact speed. While injury can be expected to correlate more highly with ΔV than speed itself, there are a number of reasons for this

*The contingency coefficient was used even when the independent variable existed on an ordinal or interval scale in order to provide uniformity and comparability across analyses.

result. First regarding rollovers, it had been shown that injury and death were more probable as the extent of rollover increased; it is most likely that higher speeds were conducive to more extended rollovers. Regarding nonroll impacts (as well as compound rollovers), to the extent that the object struck was immovable and the vehicle stopped at impact, ΔV is directly related to impact speed. Finally, higher speeds for the primary impact are likely to be associated with higher speeds for subordinate impacts and a rougher off-road traversal in general.

TABLE 6-6 SEVEREST INJURY BY IMPACT SPEED

	Injury			Total	Injured		% Killed
Speed (MPH)	None	Nonfatal	Fatal		N	%	
0 - 10	421	240	4	665	244	36.7	0.6
11 - 20	899	894	39	1,832	933	50.9	2.1
21 - 30	1,097	1,489	100	2,686	1,589	59.2	3.7
31 - 40	483	815	101	1,399	916	65.5	7.2
41 - 50	218	369	80	667	449	67.3	12.0
51 - 60	71	109	35	215	144	67.0	16.3
60+	22	44	11	77	55	71.4	14.3
Total	3,211	3,960	370	7,541	4,330	57.4	4.9

$$X^2_{12} = 401.15 \text{ (S)}, \quad C = 0.22$$

The relation between primary impact speed and severest injury is shown graphically in Figure 6-1. This figure shows the injury and the fatality rates for the midpoints of each impact speed grouping.

The proportion of injury accidents was related to impact speed using a logarithmic regression model, which accounted for 99 percent of the injury rate variance. In addition to providing a better least squares fit than a linear model ($r^2 = .81$), other properties of the logarithmic model are preferable to those of a linear one. Specifically, the logarithmic curve

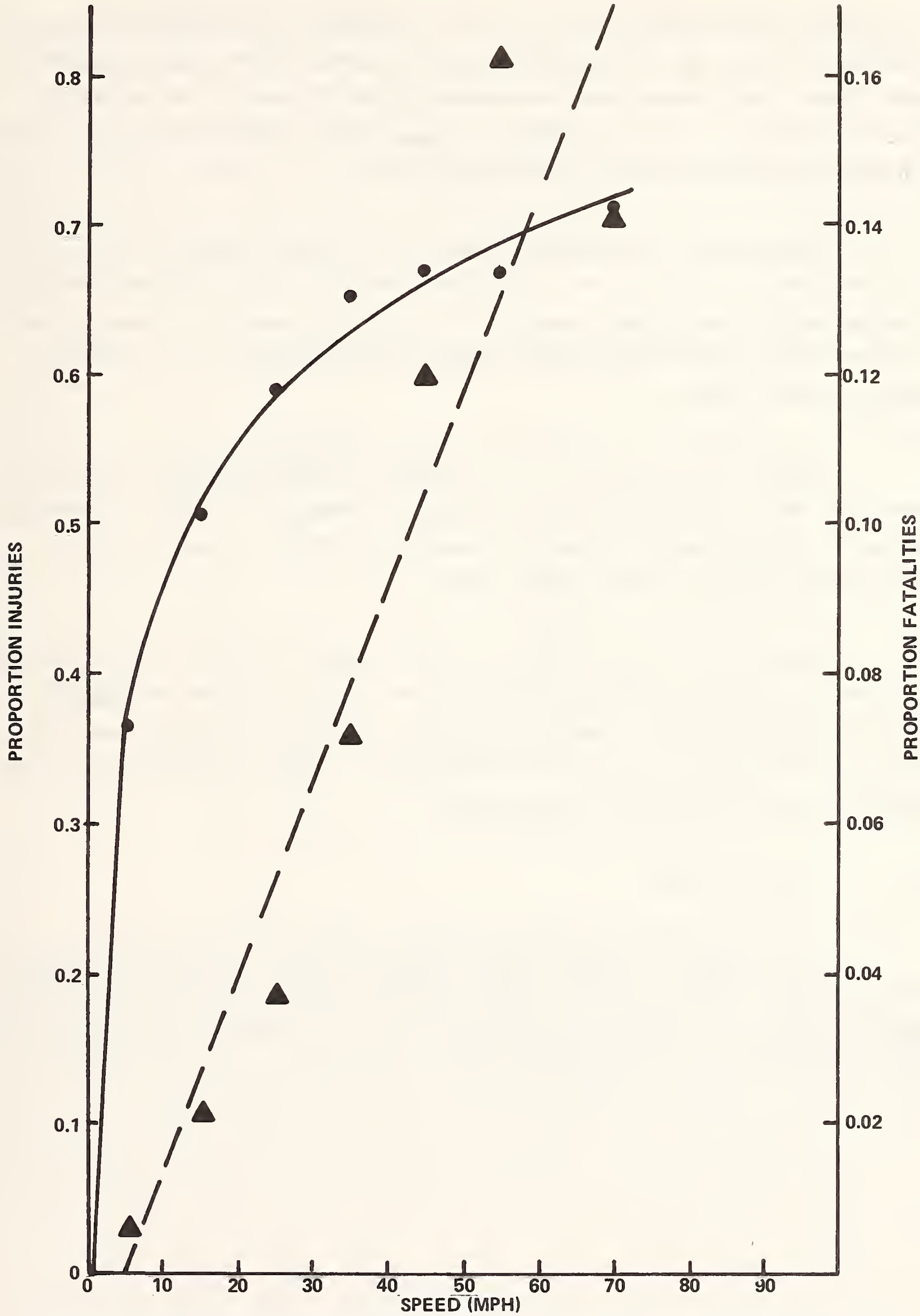

Figure 6-1 PROPORTION OF INJURY AND FATAL INJURY ACCIDENTS VERSUS IMPACT SPEED

provides for a threshold of injury, i.e., an impact speed can be calculated below which there was no indicated chance of injury. For these primary impact data, the threshold was determined to be 0.31 MPH, or in practical terms, no threshold. The least squares linear model, however, predicted a 43 percent chance of injury in 0 MPH impacts.

Because of the curvilinear shape of the relationship of injury to impact speed, it can be seen that speed changes had the greatest effect on injury in the lower speed ranges. That is, an increment in impact speed of 10 MPH would have a much greater effect on impacts below, say, 20 MPH than one above 50 MPH.

Regarding the proportion of fatalities, the linear model gave a better fit ($r^2 = .90$) than did the logarithmic model ($r^2 = .78$). Evidently, the fatality rates were low enough to avoid the effect of the 100 percent ceiling which influenced the injury rates.

Finally, the data in Table 6-6 show that although severity increased with impact speed, the number of injuries and fatal accidents was highest in the middle speed ranges. Almost 80 percent of the injuries were associated with primary impacts in the 11 to 40 MPH range. Seventy-six percent of the fatalities were in the 21 to 50 MPH range.

6.2.3 Area of Impact

The analyses of impact area and object struck are applicable only to nonroll primary impacts. There were 4,220 such accidents in which the severest injury was known. Of these, area of impact for the primary impact was known in 4,146. The results are in Table 6-7.

The presence of a number of top impacts was somewhat disturbing since rollovers were excluded and since top damage should only be coded when the direction of force is from the top of the vehicle towards the bottom. One possibility includes objects falling on the vehicle such as an impacted pole; in this instance, however, the primary impact is normally the initial contact with the pole wich would be coded as a frontal impact. It is also possible that coding errors contributed to this category. In any case, the number of such accidents is low and can be disregarded.

TABLE 6-7 SEVEREST INJURY BY IMPACT AREA FOR NONROLL IMPACTS

Area	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Front	1,119	1,264	87	2,470	1,351	54.7	3.5
Right	380	229	25	634	254	40.1	3.9
Back	82	30	1	113	31	27.4	0.9
Left	278	193	21	492	214	43.5	4.3
Top	9	19	4	32	23	71.9	12.5
Undercarriage	239	159	7	405	166	41.0	1.7
Total	2,107	1,894	145	4,146	2,039	49.2	3.5

$X^2_8 = 96.38$ (S), $C = .15$ (Tops excluded)

Of the remaining impacts, frontals had the highest injury rate and rear impacts the lowest. Frontal impacts were also associated with most of the injuries and most of the deaths. While side impacts had considerably lower injury rates than did frontals, their fatality rates were somewhat higher. However, the difference between front and side impacts in terms of proportion killed was tested and found to be not significant ($X^2_1 = 0.69$). Finally, right and left side impacts were compared; this difference was not statistically significant ($X^2_2 = 1.34$).

The results at the bottom of the table show a meaningful, significant, overall effect of impact area on injury; however, the major part of the effect was due to frontals versus all other impacts (X_2^2 = 81.94, C = 0.14).

Before proceeding, it should be noted that the coded data allowed for far more precise localization of the primary impact by including the specific horizontal area component of the CDC.* This provides for specifications such as center front, right side of the passenger compartment, etc., and gives more sensitive results. For example, there were 350 center front impacts with an injury rate of 62.3 percent and a fatality rate of 6.3 percent; this can be contrasted with the 1,015 distributed front impacts with corresponding rates of 53.2 and 3.7 percent. It was decided, however, not to explore this combination code in detail because; (1) it yields some 40 tabular cells and becomes unwieldy in application, and (2) it provides a level of detail which greatly exceeds that which can be controlled by the highway engineer.

Another impact characteristic analyzed in terms of injury was the direction of force. Although it bore a statistically significant relationship to injury, it too was excluded from further analysis. First, the code is ambiguous unless combined with impact area; for example, a 2 o'clock impact may involve the front, the front fender, the passenger compartment, etc. Second, it is a 12-valued code (excluding rollovers) and is more difficult to manage than is impact area. Third, it did not correlate with injury as well as did impact area.

6.2.4 Object Struck

The object struck by the vehicle involved in a single vehicle accident would be expected to affect injury. For equivalent impact speeds, larger ΔV's would be obtained from contacts with more rigid objects, and thus, a higher resultant severity would be anticipated. Table 6-8 gives the injury associated with contact with selected roadside objects; the objects shown were ones which had more than fifty data points.

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*Collision Deformation Classification as described in Society of Automotive Engineers, Inc., SAE J224a, 1972.

In general, the results confirm the view that the nonyielding objects are the most hazardous ones. By far the greatest hazard was presented by bridge/overpass entrances; three-fourths of the impacts resulted in at least one injury, and the fatality rate was twice that for trees and four times the average rate. Trees, field approaches (raised driveways), culverts, and embankments all had injury rates well above the average. Of these, trees and culverts had high fatality rates as well. Notably lower injury rates were found for brush, guardrails, fences, and small sign posts.

TABLE 6-8 SEVEREST INJURY BY OBJECT STRUCK IN NONROLLOVER ACCIDENTS

	Injury			Total	Injured		% Killed
Object	None	Nonfatal	Fatal		N	%	
B/O* Entrance	22	52	14	88	66	75.0	15.9
Tree	214	405	48	667	453	67.9	7.2
Field Approach	25	49	1	75	50	66.7	1.3
Culvert	87	130	14	231	144	62.3	6.1
Embankment	172	216	18	406	234	57.6	4.4
Wooden Utility Pole	292	292	14	598	306	51.2	2.3
B/O* Siderail	40	40	2	82	42	51.2	2.4
Rock(s)	37	35	1	73	36	49.3	1.4
Ditch	188	176	4	368	180	48.9	1.1
Ground	79	69	5	153	74	48.4	3.3
Trees and Brush	157	93	5	255	98	38.4	2.0
Guardrail	194	85	5	284	90	31.7	1.8
Fence	246	78	1	325	79	24.3	0.3
Small Sign Post	59	16	1	76	17	22.4	1.3
Overall	1,812	1,736	133	3,681	1,869	50.8	3.6

$X^2_{12} = 321.75$ (S)**, C = .28

*B/O means bridge or overpass

**Object types were grouped to provide higher expected values: B/O entrance plus trees, field approach plus culverts, B/O siderails plus rocks plus ground, and the last four categories.

The single object type presenting the most serious problem in terms of injury and death frequencies was single trees; they accounted for almost one-fourth of the injuries and over one-third of the fatal accidents in these nonrollover accidents. Next in order of decreasing importance were wooden utility poles, embankments, ditches, and culverts. Together, these five types of objects accounted for 70 percent of the tabulated injuries. Bridge/overpass entrances, trees, culverts, embankments, and wooden utility poles accounted for 81 percent of the tabulated fatal accidents.

6.2.5 Summary of Impact Effects

Four impact characteristics were chosen as primary factors affecting injury. A summary presentation of the results is given in Table 6-9. It shows the most profound determinants of injury were impact behavior and object struck followed by impact speed and then impact area.

TABLE 6-9 SUMMARY OF IMPACT EFFECTS ON INJURY

Impact Factor	Contingency Coefficient	Status for: Low Injury Rate	Status for: High Injury Rate	Comments
Behavior	0.29 (S)	Nonroll impacts; thru and over, continue	Extended and compound roll-overs	Taken as two groups, roll-overs were more hazardous than nonroll impacts
Object Struck	0.28 (S)	Small sign posts, fence, guardrail, trees and brush	B/O entrance, tree, field approach, culvert, embankment	
Speed	0.22 (S)	Low speed	High speed	Most of the increase in injury rates was reached before 40 MPH.
Area	0.15 (S)	Rear was best, then under-carriage and sides	Front	

7. FACTORS INFLUENCING INJURY

This section consists of numerous tables each relating the most severe occupant injury to a driver, road, or roadside factor. For each table, the statistical significance of the relationship was tested. The resultant chi-square value and the contingency coefficient are given at the bottom of the table with a specification of significant (S) or not significant (NS); all testing was done at the .05 level. To provide some perspective recall that the contingency coefficients for impact characteristics ranged from 0.15 to 0.29.

While all statistics were based on all three injury groups (no injury, non-fatal injury, and fatal injury), most of the discussion pertains to the injury rate rather than the fatality rate. This is because the number of fatal accidents was limited thereby allowing randomness to mask systematic relationships. Note that the construction of the tables is such that the fatality rate does contribute to the injury rate.

It might be noted here that the large number of tests performed in this section is conducive to Type I errors. That is, if enough tests are done even though no relationships exist, some of them will show "significance" by chance alone. Thus, the test results must be viewed with caution in this regard, and it would be well for the reader to see if the results "make sense" rather than taking the test results solely at face value.

Most of the results presented below are self-explanatory. Because of this and the number of tables involved, only brief comments are given. This should not be construed so as to lessen the importance of these findings. A tabular summary of the results concludes the section.

7.1 Driver-Related Variables

Table 7-1 clearly shows that the injury rate was higher when drivers were reported as asleep or tired. The fatality rate was also higher when drivers were asleep. It is well to bear in mind that while this table addresses driver condition, the injury variable pertains to the most serious injury among all occupants of the vehicle.

TABLE 7-1 SEVEREST INJURY BY DRIVER CONDITION

	Injury				Injured		
Condition	None	Nonfatal	Fatal	Total	N	%	% Killed
Asleep	371	490	42	903	532	58.9	4.7
Tired	49	68	3	120	71	59.2	2.5
Neither	960	902	35	1,897	937	49.4	1.8
Overall	1,380	1,460	80	2,920	1,540	52.7	2.7

$X_2^2 = 35.15$ (S) C = 0.11 (Asleep and tired grouped)

Table 7-2 shows the relationship between driver drinking status and injury. In it, HBD denotes that the driver was reported as "had been drinking", but was not cited for a drinking violation. HBD-contributory was coded when the drinking was reported as contributory to the accident. Finally, DWI was coded when the driver was cited for "driving while intoxicated".

The association between drinking status and injury was statistically significant and the contingency coefficient relatively high. Most of the effect was attributable to a simple drinking-not drinking comparison ($X_2^2 = 177.17$, C = .17). The indicated low fatality rate for DWI's is probably an artifact associated with a delay in reporting a DWI citation when an autopsy is involved.

TABLE 7-2 SEVEREST INJURY BY DRINKING STATUS

Status	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Not[a] Drinking	1,786	1,786	61	3,633	1,847	50.8	1.7
HBD	315	458	59	832	517	62.1	7.1
HBD-Contributory	254	402	63	719	465	64.7	8.8
DWI	278	605	20	903	625	69.2	2.2
Overall	2,633	3,251	203	6,087	3,454	56.7	3.3

$X^2_6 = 254.53$ (S) C = .20

Table 7-3 shows a significant interaction between driver age and injury. However, the strength of the relationship was limited. The table shows that the injury and fatality rates were essentially constant up through age 35, beyond which both increased. Recomputing the chi-square after combining the first five age groups gave a value of 17.46 on only eight degrees of freedom (C = 0.05).

TABLE 7-3 SEVEREST INJURY BY DRIVER AGE

Driver Age	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
0-16	178	211	18	407	229	56.3	4.4
17-18	408	493	36	937	529	56.5	3.8
19-20	438	566	43	1,047	609	58.2	4.1
21-25	759	852	90	1,701	942	55.4	5.3
26-35	687	860	69	1,616	929	57.5	4.3
36-55	603	784	83	1,470	867	59.0	5.6
56-65	130	179	24	333	203	61.0	7.2
66-98	57	101	13	171	114	66.7	7.6
Overall	3,260	4,046	376	7,682	4,422	57.6	4.9

$X^2_{14} = 24.95$ (S) C = 0.06

Table 7-4 is a cross-tabulation of injury and driver sex. It shows that the injury rate was five percent higher for vehicles driven by females. The difference in fatality rates was in the opposite direction but was quite small.

TABLE 7-4 SEVEREST INJURY BY DRIVER SEX

	Injury				Injured		
Driver Sex	None	Nonfatal	Fatal	Total	N	%	% Killed
Male	2,663	3,136	305	6,104	3,441	56.4	5.0
Female	627	939	75	1,641	1,014	61.8	4.6
Overall	3,290	4,075	380	7,745	4,455	57.5	4.9

$X_2^2 = 17.82$ (S) $C = 0.05$

Table 7-5 gives the effect of road familiarity on injury. The overall effect was small and not statistically significant. It might be noted that the injury was somewhat low for first time drivers, but this was not tested. Such post hoc testing was thought to be inappropriate since it would have been conducted in response to differences already seen to exist. Since such differences can arise due to random effects, their testing could lead to unwarranted credibility.

Note that some chi-square statistics were computed in an after-the-fact way. Examples are the grouping of the three drinking categories and the combining of the younger drivers. This, however, is a different matter to which the above discussion does not apply. Rather, this procedure was applied after overall significance was obtained; it represented an attempt to further detail the primary source of the overall chi-square value. Regarding the drinking status analysis, the overall chi-square was 254 on six degrees of freedom. Then it was shown that roughly two-thirds of this value was accounted for by only two degrees of freedom thereby demonstrating that the primary effects were due to the difference between drinkers and nondrinkers, rather than differences among the drinkers.

TABLE 7-5 SEVEREST INJURY BY ROAD FAMILIARITY

Familiarity	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
Daily	872	1,006	71	1,949	1,077	55.3	3.6
1+ per week	658	859	59	1,576	918	58.2	3.7
1+ per month	433	562	30	1,025	592	57.8	2.9
Rarely	538	673	33	1,244	706	56.8	2.7
Never Before	373	381	28	782	409	52.3	3.6
Overall	2,874	3,481	221	6,576	3,702	56.3	3.4

$X_8^2 = 13.97$ (NS) $C = .05$

Trip type was examined in Table 7-6. The lowest injury rates were associated with trips to or from work. The highest injury rate was for social or recreational trips. It is possible that this value was inflated due to a high proportion of drinkers.

TABLE 7-6 SEVEREST INJURY BY TRIP TYPE

Trip Type	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
Home to Work	251	252	17	520	269	51.7	3.3
Work to Home	270	282	20	572	302	52.8	3.5
Business - Local	289	331	19	639	350	54.8	3.0
Business - Long Distance	355	402	26	783	428	54.7	3.3
Shopping	94	120	6	220	126	57.3	2.7
Social or Recreational	1,382	1,844	136	3,362	1,980	58.9	4.0
Touring	249	294	40	583	334	57.3	6.9
Overall	2,890	3,525	264	6,679	3,789	56.7	4.0

$X_{12}^2 = 33.76$ (S) $C = .07$

The final table in this group is Table 7-7 which shows the effects of vehicle type. While the contingency coefficient was not large, the effects were significant. A number of additional tests were performed which were not subject to the "*post hoc*" concern in that they were based on natural groupings of vehicle types rather than observed effects on injury.

The difference between cars and trucks was not statistically significant ($X_2^2 = 4.10$), nor were within car differences ($X_6^2 = 7.58$). There was, however, a significant difference within truck types, with the heavy trucks having the lowest injury rate ($X_4^2 = 17.94$). This effect may, in part, be due to fewer occupants in heavy trucks.

TABLE 7-7 SEVEREST INJURY BY VEHICLE TYPE

Vehicle Type	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Cars:							
Sports or Subcompact	456	591	57	1,104	648	58.7	5.2
Compact	529	643	60	1,232	703	57.1	4.9
Intermediate	529	594	60	1,183	654	55.3	5.1
Full Size	730	806	64	1,600	870	54.4	4.0
Utility Vehicle	77	99	11	187	110	58.8	5.9
Trucks:							
Light	515	718	81	1,314	799	60.8	6.2
Van, Motor Home	109	162	11	282	173	61.3	3.9
Heavy	302	324	20	646	344	53.3	3.1
Overall	3,247	3,937	364	7,548	4,301	57.0	4.8

$X_{14}^2 = 30.35$ (S) $\quad C = .06$

Summarizing, the greatest effect was the higher injury rate for drinking drivers; the contingency coefficient was 0.20. Following that was driver condition with higher rates for tired drivers and those who fell asleep. It seems reasonable that this effect might be partially due to sleeping, drinking drivers. Smaller effects were found for driver age, sex, and trip type. Road familiarity was not shown to influence injury. Vehicle type also had a limited effect, with the occupants of heavy trucks less likely to suffer an injury.

7.2 Road Characteristics

The first few tables pertain to ambient conditions. Table 7-8 shows that the overall effects of lighting did not significantly influence injury. However, it was of interest to make a simple comparison between day and night accidents. The result was significant ($X_2^2 = 6.30$) with a slightly higher injury rate at night than during the day.

TABLE 7-8 SEVEREST INJURY BY LIGHT CONDITIONS

	Injury				Injured		
Lighting	None	Nonfatal	Fatal	Total	N	%	% Killed
Day	1,782	2,036	163	3,981	2,199	55.2	4.1
Dawn	86	82	8	176	90	51.1	4.5
Dusk	66	94	6	166	100	60.2	3.6
Night:							
Lighted	48	60	4	112	64	57.1	3.6
Not Lighted	1,041	1,255	130	2,426	1,385	57.1	5.4
Overall	3,023	3,527	311	6,861	3,838	55.9	4.5

$X_8^2 = 10.58$ (NS) C = .04

Table 7-9 shows a significant association between injury and weather conditions; the contingency coefficient was 0.08. The most notable effects were the high injury rate for fog and the low rate in snow. The fatality rate was highest in clear weather. The results suggest that, aside from fog, bad weather may have been conducive to increased driver caution in the form, for example, of lower speeds.

TABLE 7-9 SEVERFST INJURY BY WEATHER CONDITIONS

	Injury				Injured		
Weather	None	Nonfatal	Fatal	Total	N	%	% Killed
Clear	2,705	3,453	336	6,494	3,789	58.3	5.2
Windy	80	60	5	145	65	44.8	3.4
Rain	347	324	24	695	348	50.1	3.5
Snow	146	108	6	260	114	43.8	2.3
Fog	49	92	4	145	96	66.2	2.8
TOTAL	3,327	4,037	375	7,739	4,412	57.0	4.8

$X^2_8 = 56.15$ (S) $\quad C = .08$

A related variable is road condition; it is shown in Table 7-10 that the effects were significant and the strength of the relationship was greater than that for weather conditions. As before, the data show that worsening conditions were conducive to lower injury and fatality rates.

TABLE 7-10 SEVERFST INJURY BY ROAD CONDITION

	Injury				Injured		
Condition	None	Nonfatal	Fatal	Total	N	%	% Killed
Dry	2,518	3,333	331	6,182	3,664	59.3	5.4
Wet	451	439	32	922	471	51.1	3.5
Ice/Snow	372	271	12	655	283	43.2	1.8
Overall	3,341	4,043	375	7,759	4,418	56.9	4.8

$X^2_4 = 84.97$ (S) $\quad C = .10$

Table 7-11 was developed to clarify the relative effects of weather and road conditions on injury.

TABLE 7-11 INJURY BY WEATHER AND ROAD CONDITION

	Road Condition					
	Dry		Wet		Wintry	
Weather	N	% Injured	N	% Injured	N	% Injured
Clear	6,011	59.2	193	52.3	258	43.0
Rain	-	-	660	49.8	29	48.3
Snow	-	-	16	62.5	239	42.3

For clear weather, the injury rate showed a considerable drop from dry to wet to wintry roads. This presumably reflected increased driver caution in the form of reduced speeds with worsening road conditions.

Now consider the effect of wet roads and rain. In clear weather, the injury rate dropped seven percent from dry roads to wet; on wet roads, the injury rate dropped only another two percent. Thus, the effect of wet roads was greater than the effect of rain in addition to wet roads.

Regarding snow fall and wintry surfaces, in clear weather the injury rate dropped 16 percent from dry surfaces to wintry ones. In contrast, there was essentially no change in the injury rate from clear weather to snowfall on wintry road surfaces.

Thus, the results show that the primary factor was the road condition with little or no effect of precipitation.

The next set of tables contains variables reflecting road alignment, first horizontal, then vertical. Table 7-12 allows a comparison of straight roads with curves to the left and to the right. There was a weak but statistically significant interaction between alignment and injury. This was primarily due to the straight versus curve comparison ($X_2^2 = 17.91$); the difference between left and right curves was not significant ($X_2^2 = 3.59$).

TABLE 7-12 SEVEREST INJURY BY HORIZONTAL ALIGNMENT

Alignment	Injury			Total	Injured		% Killed
	None	Nonfatal	Fatal		N	%	
Tangent	2,008	2,259	203	4,470	2,462	55.1	4.5
Left Curve	715	1,017	107	1,839	1,124	61.1	5.8
Right Curve	523	652	64	1,239	716	57.8	5.2
Overall	3,246	3,928	374	7,548	4,302	57.0	5.0

$X_4^2 = 21.48$ (S) $C = .05$

Table 7-13 shows a significant relationship between horizontal curve length and injury. The contingency coefficient, whose value was 0.12, was quite high among the roadway factors. The results show both the injury rate and the fatality rate were maximum for curves 1,100 to 1,500 feet long.

TABLE 7-13 SEVEREST INJURY BY LENGTH OF HORIZONTAL CURVE

Curve Length	Injury			Total	Injured		% Killed
	None	Nonfatal	Fatal		N	%	
100-200	88	115	8	211	123	58.3	3.8
300-400	108	159	15	282	174	61.7	5.3
500-600	80	96	17	193	113	58.5	8.8
700-1000	99	139	17	255	156	61.2	6.7
1100-1500	61	93	22	176	115	65.3	12.5
1600+	127	157	12	296	169	57.1	4.1
Overall	563	759	91	1,413	850	60.2	6.4

$X_{10}^2 = 20.68$ (S) $C = .12$

The next table, number 7-14, gives injury by degree of curvature* first for left curves and then for right curves. Although neither was significantly related to injury, the contingency coefficients for both curves were moderately high relative to other values obtained. Note that while the left curve data showed diminishing injury and fatality rates for sharper curves, the right curve data show no systematic effects.

TABLE 7-14 SEVEREST INJURY BY DEGREE OF CURVATURE

Curvature (degrees)	Injury				Injured		
	None	Nonfatal	Fatal	Total	N	%	% Killed
Left Curves:							
0-4	271	400	42	713	442	62.0	5.9
4-8	118	214	27	359	241	67.1	7.5
8-12	71	97	9	177	106	59.9	5.1
12+	61	59	5	125	64	51.2	4.0
Overall (Left Curves)	521	770	83	1,374	853	62.1	6.0
Right Curves:							
0-4	194	254	24	472	278	58.9	5.1
4-8	103	107	10	220	117	53.2	4.5
8-12	52	64	13	129	77	59.7	10.1
12+	41	50	3	94	53	56.4	3.2
Overall (Right Curves)	390	475	50	915	525	57.4	5.5
Overall	911	1,245	133	2,289	1,378	60.2	5.8

Left Curves $X_6^2 = 11.61$ (NS) $C = .09$

Right Curves $X_6^2 = 8.67$ (NS) $C = .10$

* The tabulated intervals are, strictly speaking, above zero to 4, above 4 to 8, etc.

Table 7-15 shows the relationship of injury to vertical alignment. The major effect here was the difference from level to grades to vertical curves (X_4^2 = 18.70). The injury rate was lowest for level roads and highest for vertical curves. A comparison of upgrades versus downgrades was not statistically significant (X_2^2 = 2.92).

TABLE 7-15 SEVEREST INJURY BY VERTICAL ALIGNMENT

	Injury				Injured		
Alignment	None	Nonfatal	Fatal	Total	N	%	% Killed
Level	905	954	92	1,951	1,046	53.6	4.7
Upgrade	416	484	37	937	521	55.6	3.9
Downgrade	625	802	76	1,503	878	58.4	5.1
Up on Crest	149	197	22	368	219	59.5	6.0
Down on Crest	171	259	27	457	286	62.6	5.9
Up on Sag	108	132	16	256	148	57.8	6.3
Down on Sag	79	113	14	206	127	61.7	6.8
Overall	2,453	2,941	284	5,678	3,225	56.8	5.0

X_{12}^2 = 23.70 (S) C = .06

In Table 7-16, injury is given as a function of grade for up and downgrades separately. Both contingency coefficients were low and neither was significant. (In both sets of computations, the last two tabular rows were combined.) Nonetheless, both data sets show increasing injury rates with increasing grade. This suggests the effects may be real.

The three remaining tables in this section pertain to road configuration; they are lane width, number of lanes, and road division. Table 7-17 shows injury as a function of lane width. The contingency coefficient was small and not statistically significant. The injury rate was essentially uniform except for the extreme lane widths where the number of observations was limited. The fatality rate, however, increased almost monotonically with increasing lane width. It was difficult to know if this was a real effect; it could have reflected higher travel speeds on roads with wider lanes.

TABLE 7-16 SEVEREST INJURY BY GRADE

Grade	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed*
Upgrade:							
1-3	298	341	27	666	368	55.3	4.1
4-6	60	76	6	142	82	57.7	4.2
7+	1	2	0	3	2	66.7	0.0
Overall (Up)	359	419	33	811	452	55.7	4.1
Downgrade:							
1-3	436	521	53	1,010	574	56.8	5.2
4-6	103	140	12	255	152	59.6	4.7
7+	7	11	0	18	11	61.1	0.0
Overall (Down)	546	672	65	1,283	737	57.4	5.1
Overall	905	1,091	98	2,094	1,189	56.8	4.7

Upgrade: $X^2_2 = 0.35$ (NS) C = .02

Downgrade: $X^2_2 = 1.30$ (NS) C = .03

TABLE 7-17 SEVEREST INJURY BY LANE WIDTH

Width (ft.)	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
Less than 8.5	35	65	3	103	68	66.0	2.9
8.5-9.5	250	317	23	590	340	57.6	3.9
9.5-10.5	547	686	57	1,290	743	57.6	4.4
10.5-11.5	415	541	52	1,008	593	58.8	5.2
11.5-16.5	1,957	2,291	230	4,478	2,521	56.3	5.1
Greater than 16.5	24	41	4	69	45	65.2	5.8
Overall	3,228	3,941	369	7,538	4,310	57.2	4.9

$X^2_{10} = 12.73$ (NS) C = .04

Table 7-18 shows a significantly lower injury rate on divided roads. The fatality rate was also lower, but in both cases the effect was not large.

TABLE 7-18 SEVEREST INJURY BY ROADWAY DIVISION

Divided	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
No	2,781	3,482	327	6,590	3,809	57.8	5.0
Yes	526	547	50	1,123	597	53.2	4.5
Separate Road	25	22	2	49	24	49.0	4.1
Overall	3,332	4,051	379	7,762	4,430	57.1	4.9

$X_2^2 = 8.46$ (S) C = 0.03 (Separate roads excluded)

Multilane roads had fewer injury-producing accidents than did single lane roads; this is shown in Table 7-19. As was found for lane width, however, the effect was not large. Comparing this table with the previous one suggests they both measure the same thing: divided multilane roads versus undivided single lane roads.

TABLE 7-19 SEVEREST INJURY BY NUMBER OF THROUGH LANES IN TRAVELED DIRECTION

Number of Lanes	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
1	2,788	3,474	326	6,588	3,800	57.7	4.9
2	571	598	54	1,223	652	53.3	4.4
3+	5	2	0	7	2	28.6	0.0
Overall	3,364	4,074	380	7,818	4,454	57.0	4.9

$X_2^2 = 8.67$ (S) C = 0.03 (2 and 3 lanes combined)

In summary, the injury rate and the fatality rate decreased from dry to wet to wintry road surfaces. Most weather effects were due to the mediating influence of road surface conditions rather than direct atmospheric effects. Except for fog, the injury rate decreased with worsening weather and road surface conditions.

Regarding horizontal alignment, curves were more hazardous than straight roads in terms of injury rates. The length of curves had a notable influence on injury, but the relationship was not a systematic one; the highest injury and fatality rates were found for 1,100 to 1,500 foot curves. As the degree of curvature increased for left curves, the injury and fatality rates became smaller; however, the effect was not found to be statistically significant.

Regarding vertical alignment, injury rates were lowest for level roads and highest for vertical curves. Although not significant, the data suggested that higher injury rates might be expected as grade increases.

The relationship between lane width and injury was not found to be statistically significant; nonetheless, there was a fairly convincing increase in the fatality rate as lane width increased. Finally, injury rates were found to be somewhat higher on undivided roads and on single lane roads.

By way of an overview regarding injury rates, there were instances of undesirable conditions being associated with either higher or lower injury rates. The rates were low for wintry road surfaces but high in fog. Rates were higher on curved roads than straight, but they appeared to decrease as the degree of curvature increased. On the other hand, injury rates increased with vertical complexity. While the sample fatality rates increased with lane width, the injury rates were low for divided roads and for multilane roads.

While there was insufficient time to carry out analyses probing this kind of question, the nature of these findings suggests that drivers adapted, to some degree, to hazardous conditions, and that this was most likely to occur when the cause of the risk was most readily seen by the driver. Note that as with essentially all findings and resultant views expressed in this report, these considerations pertain to injury and may, or may not, apply to accident occurrence.

7.3 On-Road Events and Departure Characteristics

Nine tables are presented in this section. The first five pertain to predeparture events and the remainder pertain to the departure itself. Table 7-20 gives injury distributions for each maneuver type. The indicated chi-square and related contingency coefficient were calculated after turns were grouped and external influences were grouped. Relative to values for other tables, the contingency coefficient was moderately high. Most notable here was the relatively high injury rate when vehicles departed with no known attempted corrective response. On the other hand, turns had the lowest injury rate, probably reflecting reduced road speed when turning.

TABLE 7-20 SEVEREST INJURY BY VEHICLE MANEUVER

Maneuver	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Control Failure or Attempted Correction	1,745	2,024	180	3,949	2,204	55.8	4.6
No Corrective Response	834	1,209	124	2,167	1,333	61.5	5.7
Either	302	442	65	809	507	62.7	8.0
Turn:							
Wide	61	40	0	101	40	39.6	0.0
Short	5	4	0	9	4	44.4	0.0
Protracted	7	5	1	13	6	46.2	7.7
Overall	73	49	1	123	50	40.7	0.8
External Influence:							
End of Path	7	4	0	11	4	36.4	0.0
Traffic Control	14	10	1	25	11	44.0	4.0
Veh. Ahead (Opp.)	114	104	3	221	107	48.4	1.4
Veh. Ahead (Same)	113	71	2	186	73	39.2	1.1
Veh. to Side	22	19	0	41	19	46.3	0.0
Veh. at Intersection	13	15	0	28	15	53.6	0.0
Animal	83	100	1	184	101	54.9	0.5
Overall	366	323	7	696	330	47.4	1.0
Overall	3,320	4,047	377	7,744	4,424	57.1	4.9

$X_8^2 = 101.40$ (S) $\qquad C = 0.11$

Table 7-21 gives injury information for vehicles which left tire marks on the road before the first departure and for vehicles which did not. Those with tire marks were usually either out of control or were braking heavily. There was a four percent difference in injury rates; the vehicles with tire marks had the lower rate.

TABLE 7-21 SEVEREST OCCUPANT INJURY BY TIRE MARKS

	Injury				Injured		
Tire Marks	None	Nonfatal	Fatal	Total	N	%	% Killed
Yes	1,093	1,222	105	2,420	1,327	54.8	4.3
No	2,072	2,701	268	5,041	2,969	58.9	5.3
Overall	3,165	3,923	373	7,461	4,296	57.6	5.0

$X_2^2 = 12.45$ (S) $C = 0.04$

For those vehicles with predeparture tire marks, the distance from the point of origin of the marks to the point of departure was measured. Table 7-22 shows the injury distributions as a function of this distance.

TABLE 7-22 SEVEREST INJURY BY DISTANCE FROM ORIGIN OF TIRE MARKS

	Injury				Injured		
Distance (feet)	None	Nonfatal	Fatal	Total	N	%	% Killed
1-25	113	136	10	259	146	56.4	3.9
26-50	176	188	13	377	201	53.3	3.4
51-100	297	314	23	634	337	53.2	3.6
101-250	239	350	35	624	385	61.7	5.6
251+	48	60	11	119	71	59.7	9.2
Overall	873	1,048	92	2,013	1,140	56.6	4.6

$X_8^2 = 19.54$ (S) $C = 0.10$

Whereas the contingency coefficient was only 0.04 for the existence of tire marks, it was 0.10 for the distance from their origin. The results show the minimum injury rate was obtained when the distance was in the 26 to 100 foot range. Without further study, the reason for this was not clear. It could be speculated that vehicles with very short tire marks had very little deceleration before departure, while those with long tire marks may have had high travel speeds and were completely out of control at the point of departure. Note that the fatality rates were highly correlated with the injury rates.

In another regard, over one-third of the distances exceeded 100 feet. Given the time necessary for a driver to recognize a problem and respond to it, this suggests a substantial proportion of the drivers departed the road at least 200 feet beyond the point where the problem was initiated. In turn, this tends to substantiate the view expressed in discussing the percent of curve traversed (Section 3.4.1) that a vehicle departing a curve at one point reflects problems occurring upstream of it.

Among vehicles experiencing predeparture control failures, some did so at least in part because of a rough road surface or, more often, because the road surface was slippery, usually due to ice or snow. Table 7-23 gives the injury distributions for vehicles which had such induced control failures and those which did not.

TABLE 7-23 SEVEREST INJURY BY INDUCED CONTROL FAILURE

ICF		Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Yes:	Road	17	23	0	40	23	57.5	0.0
	Ice/Snow	457	352	18	827	370	44.7	2.2
No		2,851	3,659	357	6,867	4,016	58.5	5.2
Overall		3,325	4,034	375	7,734	4,409	57.0	4.8

$X_2^2 = 62.53$ (S) $C = 0.09$

Because of the low frequency of induced control failures, those associated with rough roads were deleted for testing purposes. The resultant contingency coefficient was moderately high relative to other tables. That the injury rate was lowest for induced control failures on slippery surfaces reflects slower travel speeds on icy and snowy roads as alluded to earlier.

Table 7-24 is the last one pertaining to on-road events. It gives the injury distribution for departures in which there was a reported vehicle breakdown, driver breakdown, or neither. It shows that the injury rate was lowest for accidents associated with vehicle breakdowns. The reason for this is unknown, but it is likely that in some instances the malfunction was detected by the driver and speed was reduced some distance before the departure occurred; a flat tire would fit this scenario.

TABLE 7-24 SEVEREST INJURY BY MALFUNCTION

	Injury				Injured		
Malfunction	None	Nonfatal	Fatal	Total	N	%	% Killed
Vehicle Breakdown	231	195	9	435	204	46.9	2.1
Driver Breakdown	387	510	43	940	553	58.8	4.6
Neither	2,751	3,374	328	6,453	3,702	57.4	5.1
Overall	3,369	4,079	380	7,828	4,459	57.0	4.9

$X_4^2 = 24.34$ (S) $C = 0.06$

The remaining tables in this section pertain to the departure itself. Table 7-25 gives injury as a function of departure angle*. The relationship between injury and departure angle as measured by the coefficient of contingency was moderately high. The injury rate was highest for very small angles; it dropped as angles increased up to 11 degrees, after which it remained relatively constant. Although the fatality rate was more variable, it seemed to follow a similar pattern.

TABLE 7-25 SEVEREST INJURY BY DEPARTURE ANGLE

	Injury				Injured		
Angle	None	Nonfatal	Fatal	Total	N	%	% Killed
0-2°	109	177	20	306	197	64.4	6.5
3-5	274	386	59	719	445	61.9	8.2
6-8	450	599	61	1,110	660	59.5	5.5
9-11	446	464	40	950	504	53.1	4.2
12-14	186	231	23	440	254	57.7	5.2
15-20	394	431	36	861	467	54.2	4.2
21-29	297	328	16	641	344	53.7	2.5
30-45	233	259	7	499	266	53.3	1.4
46-79	105	104	6	215	110	51.2	2.8
80-90	53	62	2	117	64	54.7	1.7
Overall	2,547	3,041	270	5,858	3,311	56.5	4.6

$X^2_{18} = 71.96$ (S) $C = 0.11$

Table 7-26 gives injury by departure attitude. It shows the likelihood of at least one injury was seven percent higher for tracking vehicles as compared to nontracking vehicles. The fatality rate was also somewhat higher for the trackers.

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* In this analysis and the two that follow, the departure characteristics pertain to the first departure in the accident.

TABLE 7-26 SEVEREST INJURY BY DEPARTURE ATTITUDE

Attitude	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Tracking	1,839	2,507	237	4,583	2,744	59.9	5.2
Not Tracking	971	987	82	2,040	1,069	52.4	4.0
Overall	2,810	3,494	319	6,623	3,813	57.6	4.8

$X_2^2 = 33.15$ (S) $C = 0.07$

It is of some importance to point out that earlier discussions implied that nontracking and large departure angles were undesirable. They both tend to reflect reduced vehicle control and they both reduce the likelihood of avoiding impacts in the first departure. On this basis, it is likely that they both reduce the likelihood of continuing the trip unscathed after an initial departure has occurred. But, in contrast to this, the above results show that when departing vehicles did not get away, these two conditions (nontracking and large angles) were associated with accidents which were less severe.

Table 7-27 gives injury as a function of departure point. The chi-square value was computed after deleting lane drops. It was not significant, and the associated contingency coefficient was very small.

TABLE 7-27 SEVEREST INJURY BY DEPARTURE POINT

Departure Point	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Right Side	2,091	2,522	245	4,858	2,767	57.0	5.0
Left Side	1,022	1,250	109	2,381	1,359	57.1	4.6
Median	168	207	22	397	229	57.7	5.5
Lane Drop	0	3	0	3	3	100.0	0.0
Intersection	74	86	4	164	90	54.9	2.4
Overall	3,355	4,068	380	7,803	4,448	57.0	4.9

$X_6^2 = 3.40$ (NS) $C = 0.02$

The final results in this section appear in Table 7-28. The major finding here was that the injury rate was lowest for single departure accidents; when contrasted to the other configurations, the difference accounted for most of the overall chi-square value (X_2^2 = 30.77). This was also the configuration which contained the vast majority of the accidents. Note that the second most frequent configuration, a double departure involving both sides of the road, had one of the highest injury rates. Caution is advised regarding the rates for multiple departures and those involving crossing medians in that they were based on few observations.

TABLE 7-28 SEVEREST INJURY BY DEPARTURE CONFIGURATION

Configuration	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
Single Dep.	2,583	2,946	252	5,781	3,198	55.3	4.4
Dep. + Return	129	164	13	306	177	57.8	4.2
Dbl. Dep. - 1 Side	143	179	15	337	194	57.6	4.5
Mltpl. Dep. - 1 Side	2	13	2	17	15	88.2	11.8
Dbl. Dep. - 2 Sides	454	708	86	1,248	794	63.6	6.9
Mltpl. Dep. - 2 Sides	32	33	7	72	40	55.6	9.7
Cross Median	18	22	2	42	24	57.1	4.8
Prior Dep. + Cross Median	4	12	2	18	14	77.8	11.1
Overall	3,365	4,077	379	7,821	4,456	57.0	4.8

X_8^2 = 43.01 (S) C = 0.07 (Mulpl. Dep. - 1 Side, Multpl. Dep. - 2 Sides, Cross Median, and Prior Dep. + Cross Median Combined)

In summary, on-road events suggest that passive departures tended to be conducive to a greater likelihood of injury. This was true for departures with no corrective response and with no tire marks. It was also found earlier to be applicable for sleeping drivers. On this basis, one might have anticipated a high injury rate for driver breakdowns, but the data did not show this to be true. One possible explanation is that when a driver loses consciousness, he may impart uncontrolled steering inputs so that the resultant vehicle behavior is not passive.

Regarding the effects of departure characteristics, it was found that the occupants of vehicles which were tracking and those with small departure angles were more likely to sustain injury. Note that this fits the pattern of higher injury for the more passive departures. This was also true for occupants in vehicles experiencing multiple (including double) departures. Previous analysis had shown that multiple departures were more likely to occur when the vehicle was tracking and had a small departure angle. Thus, part of the higher injury rate for tracking and small angle departures may be explained by the greater incidence of multiple departures. As noted earlier, this presents somewhat of an enigma in that vehicles experiencing controlled, shallow departures, undoubtedly have a better opportunity to avoid an accident altogether, but if they do not, there is a greater likelihood of injury.

7.4 Roadside Factors

The following tables give injury distributions as a function of various roadside characteristics. The first one is shoulder width in Table 7-29. The overall chi-square was not significant and the contingency coefficient was moderate. The data do show lower injury rates for shoulders nine feet or wider, but this may be a random effect; note that the highest fatality rates were associated with the widest shoulders.

TABLE 7-29 SEVEREST INJURY BY SHOULDER WIDTH

Width (ft.)	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
None	388	499	43	930	542	58.3	4.6
1-2	344	409	36	789	445	56.4	4.6
3-4	708	907	75	1,690	982	58.1	4.4
5-6	512	720	76	1,308	796	60.9	5.8
7-8	360	517	47	924	564	61.0	5.1
9-10	524	568	56	1,148	624	54.4	4.9
11+	163	169	22	354	191	54.0	6.2
Overall	2,999	3,789	355	7,143	4,144	58.0	5.0

$X^2_{12} = 22.04$ (NS) $C = 0.06$

The next analysis, appearing in Table 7-30, was performed primarily to examine the differential effects of ditches and road fill on injury. Note that only the presence of the ditch or fill is implied here; the vehicle may, or may not, have had difficulty due to the ditch or fill. In any case, the contingency coefficient was small and lacked statistical significance. Furthermore, there was less than one percent difference in injury rate for ditch versus fill.

In spite of the similar injury experience for ditch cut roads and those built on fill, it was of interest to examine the effect of the amount of slope. Table 7-31 shows injury by slope, first for fill and then for ditches. For fill, the injury rate and the fatality rate were higher for steeper slopes. However, the chi-square was not significant and the contingency coefficient was small. For ditch cut roads, the contingency coefficient was somewhat larger, but it too lacked statistical significance. Furthermore, there was no clear systematic relationship to injury.

TABLE 7-30 SEVEREST INJURY BY ROAD CLASS

Road Class	Injury			Total	Injured		% Killed
	None	Nonfatal	Fatal		N	%	
Fill	1,757	2,167	200	4,124	2,367	57.4	4.8
Ditch	1,035	1,317	125	2,477	1,442	58.2	5.0
Rock Cut	50	79	4	133	83	62.4	3.0
Bridge	68	71	12	151	83	55.0	7.9
Tunnel	2	1	0	3	1	33.3	0.0
Retaining Wall	6	2	1	9	3	33.3	11.1
Hillside	99	145	17	261	162	62.1	6.5
Overall	3,017	3,782	359	7,158	4,141	57.9	5.0

$X^2_8 = 9.92$ (NS) $C = 0.04$ (Tunnels and retaining walls excluded.)

TABLE 7-31 SEVEREST INJURY BY SIDE SLOPE

Slope	Injury			Total	Injured		% Killed
	None	Nonfatal	Fatal		N	%	
Fill:							
1:1	49	60	6	115	66	57.4	5.2
2:1	395	536	53	984	589	59.9	5.4
3:1	303	344	29	676	373	55.2	4.3
4:1	321	370	32	723	402	55.6	4.4
6:1 or flatter	491	570	52	1,113	622	55.9	4.7
Overall	1,559	1,880	172	3,611	2,052	56.8	4.8
Ditch:							
1:1	80	107	11	198	118	59.6	5.6
2:1	231	263	23	517	286	55.3	4.4
3:1	158	220	15	393	235	59.8	3.8
4:1	175	252	26	453	278	61.4	5.7
6:1 or flatter	263	301	33	597	334	55.9	5.5
Overall	907	1,143	108	2,158	1,251	58.0	5.0

Fill $X^2_8 = 5.91$ (NS) $C = 0.04$

Ditch $X^2_8 = 7.97$ (NS) $C = 0.06$

Next, as shown in Table 7-32, the effects of fill height and ditch depth were studied. For fill, there was an apparent trend with the injury rate increasing from one foot to five feet and then remaining stable with the possible exception of slopes greater than twenty feet where the maximum rate was reached. (But the small number of observations in this last interval throws some doubt on its reliability.) The chi-square value, however, was below that required for significance.

TABLE 7-32 SEVEREST INJURY BY SIDE SLOPE HEIGHT

Height (ft.)	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Fill:							
1'	120	128	7	255	135	52.9	2.7
2	158	168	19	345	187	54.2	5.5
3	144	165	15	324	180	55.6	4.6
4-5	326	401	33	760	434	57.1	4.3
6-10	247	298	24	569	322	56.6	4.2
11-20	145	177	18	340	195	57.4	5.3
21+	42	68	10	120	78	65.0	8.3
Overall	1,182	1,405	126	2,713	1,531	56.4	4.6
Ditch:							
1'	189	206	16	411	222	54.0	3.9
2	310	326	35	671	361	53.8	5.2
3	141	236	17	394	253	64.2	4.3
4-5	182	222	19	423	241	57.0	4.5
6+	44	65	6	115	71	61.7	5.2
Overall	866	1,055	93	2,014	1,148	57.0	4.6

Fill $X^2_{12} = 11.61$ (NS) $C = 0.07$

Ditch $X^2_{8} = 15.86$ (S) $C = 0.09$

The results for ditch cut roads were statistically significant and the contingency coefficient was moderately high. On the other hand, there was again an unclear functional relationship. However, if minor perturbations are ignored, there was the general effect of lower injury rates for ditches less than three feet deep.

In comparing Tables 7-31 and 7-32, some similarities were apparent. First regarding fill; as the slope became steeper or higher, the injury rate increased. This is reasonable as slope and height are likely to be correlated. It also suggests this trend is "real" in spite of the lack of statistical significance. (While the time available precluded a regression analysis, it is likely that such an analysis, because it takes into account the ordered nature of the independent variable, would yield a significant result.)

The results for ditch cut roads were also comparable for the two tables. Whether considering depth or slope, the injury was small for shallow ditches; it increased in the middle range, then dropped down, and increased again for the deepest ditches. This may suggest both slope and depth had real effects.

Table 7-33 shows injury as related to border offset. As explained earlier, a border was defined to be nontraversable and to extend through at least 50 percent of the traveled roadside. The chi-square value, for which the last two tabled rows were combined, was significant, although contingency coefficient was not high. Generally speaking, the injury rate increased, although erratically, with border offset. As discussed in Section 4, this probably reflects higher travel speeds on roads with large offsets.

Table 3-34 shows the effect of pole offset on injury. As with border offset, the injury rate increased with pole offset. Indeed, the effect of pole offset was much greater; the contingency coefficient was the highest among all roadside factors analyzed. The fatality rate also increased fairly consistently with pole offset.

TABLE 7-33 SEVEREST INJURY BY BORDER OFFSET

Offset (ft.)	Injury				Injured		
	None	Nonfatal	Fatal	Total	N	%	% Killed
0-10'	436	451	33	920	484	52.6	3.6
11-20	379	450	41	870	491	56.4	4.7
21-30	222	233	21	476	254	53.4	4.4
31-40	96	133	18	247	151	61.1	7.3
41-60	88	121	11	220	132	60.0	5.0
61-100	53	57	6	116	63	54.3	5.2
101-300	16	33	1	50	34	68.0	2.0
301+	178	262	28	468	290	62.0	6.0
Overall	1,468	1,740	159	3,367	1,899	56.4	4.7

$X^2_{12} = 23.12$ (S) $C = 0.08$

TABLE 7-34 SEVEREST INJURY BY POLE OFFSET

Offset (ft.)	Injury				Injured		
	None	Nonfatal	Fatal	Total	N	%	% Killed
1-6'	123	122	3	248	125	50.4	1.2
7-12	278	283	20	581	303	52.2	3.4
13-18	163	158	10	331	168	50.8	3.0
19-24	111	125	10	246	135	54.9	4.1
25-30	69	85	6	160	91	56.9	3.8
31+	90	157	21	268	178	66.4	7.8
Overall	834	930	70	1,834	1,000	54.5	3.8

$X^2_{10} = 32.39$ (S) $C = 0.13$

Table 7-35 gives injury as a function of the roadside culture. Notice that the injury rate ranged from 49 percent to 66 percent, but because the vast majority of the observations were in a single category, the contingency coefficient was small. While it seemed reasonable that rocky land would be conducive to high injury and fatality rates, it was not clear why a high injury rate should be associated with high grass. Because the number of observations was small, this could be due to extraneous influences.

TABLE 7-35 SEVEREST INJURY BY ROADSIDE CULTURE

	Injury				Injured		
Culture	None	Nonfatal	Fatal	Total	N	%	% Killed
Open	2,543	3,126	309	5,978	3,435	57.5	5.2
High Grass	40	72	2	114	74	64.9	1.8
Brush	69	84	9	162	93	57.4	5.6
Light Tree Growth	108	96	9	213	105	49.3	4.2
Heavy Tree Growth	57	71	5	133	76	57.1	3.8
Rock	44	74	12	130	86	66.2	9.2
Overall	2,861	3,523	346	6,730	3,869	57.5	5.1

$X^2_{10} = 20.08$ (S) $C = 0.05$

Table 7-36 shows the injury distributions for various categories of terrain. There was little variation of the injury rate among categories containing a reasonable number of observations, and the chi-square test failed to show significance.

TABLE 7-36 SEVEREST INJURY BY TERRAIN

Terrain	Injury: None	Nonfatal	Fatal	Total	Injured: N	%	% Killed
Flat	1,210	1,364	130	2,704	1,494	55.3	4.8
Rolling	1,211	1,527	152	2,890	1,679	58.1	5.3
Hilly	255	325	32	612	357	58.3	5.2
Mountainous	62	86	12	160	98	61.3	7.5
Steep	9	6	1	16	7	43.8	6.3
Overall	2,747	3,308	327	6,382	3,635	57.0	5.1

$X^2_8 = 7.44$ (NS) $C = 0.03$

While the previous table reflected the general roadside terrain, Table 7-37 gives the terrain contour at the point of the primary impact. The chi-square was calculated after combining the last two rows; it was significant and the contingency coefficient was in a moderate range. The lowest injury rate was found for impacts occurring on the shoulder, and the highest was for impacts on down slopes.

TABLE 7-37 SEVEREST INJURY BY TERRAIN CONTOUR

Contour	Injury: None	Nonfatal	Fatal	Total	Injured: N	%	% Killed
Shoulder	296	235	25	556	260	46.8	4.5
	781	883	103	1,767	986	55.8	5.8
	258	322	23	603	345	57.2	3.8
	229	279	27	535	306	57.2	5.0
	814	1,113	109	2,036	1,222	60.0	5.4
	189	225	19	433	244	56.4	4.4
	533	646	38	1,217	684	56.2	3.1
	90	113	6	209	119	56.9	2.9
	26	35	1	62	36	58.1	1.6
	8	10	1	19	11	57.9	5.3
Overall	3,224	3,861	352	7,437	4,213	56.6	4.7

$X^2_{16} = 50.13$ (S) $C = 0.08$

Summarizing roadside factors as they relate to the incidence of injury, while shoulder widths less than nine feet showed no injury reduction, a later analysis showed accidents with the primary impact on the shoulder had a low injury rate. Further study is needed to clarify this. It should be done with a view to the fact that while the injury rate might be expected to be reduced by wider shoulders, other results showed the injury rate increased with the offset of (nontraversable) borders and poles (an example of a semi-traversable border).

While filled roads and ditch cut roads did not differ in terms of injury rates, there was some evidence that the height and slope of fill and ditches did influence injury. In particular, the injury rate appeared to increase with the height and slope of road fill. For ditch cut roads, the effect, as measured by the contingency coefficient, was stronger but more complex. Nonetheless, the injury rates for ditches no deeper than two feet were low relative to those for deeper ditches.

7.5 Summary of Factors Influencing Injury

Table 7-38 gives a summary of factors examined in this section. The variables are grouped in the order presented, but within groups they are listed in order of the contingency coefficient. For the sake of completeness and to aid comparison, impact characteristics are listed at the end of the table; also included are safety belt and ejection effects.

Overall, the largest effects on injury were associated with ejection and then impact characteristics. Following these were drinking status, pole offset, length of horizontal curve, restraint use, driver condition, maneuver, departure angle, road condition, and distance from the origin of tire marks. The remainder had contingency coefficients less than 0.10.

TABLE 7-38 SUMMARY OF FACTORS INFLUENCING INJURY RATES

Driver-Related Variables	Contingency Coefficient	Status for: High Injury Rate	Status for: Low Injury Rate	Comments
Drinking Status	0.20 (S)	Drinking	Not drinking	Highest rate for DWI. High fatality rate for HBD's.
Condition	0.11 (S)	Asleep, tired	Normal	
Trip Type	0.07 (S)	Social, touring, shopping	Home to work, work to home	
Vehicle Type	0.06 (S)	Vans, motorhomes, utility vehicles, small cars	Heavy trucks, larger cars	No significant differences among any car sizes. Results may be affected by diffusing number of occupants.
Age	0.06 (S)	Increasing above age 35	35 and lower	
Sex	0.05 (S)	Female	Male	
Road Familiarity	0.05 (NS)	Else	Never drove this road before	
Road Characteristics				
Length of Horizontal Curve	0.12 (S)	-	-	Maximum injury and fatality rate for 1,100 to 1,500 foot curves
Road Condition	0.10 (S)	Dry	Ice, snow	Wet roads had intermediate rate.
Degree of Curvature: - Right Curves	0.10 (NS)	-	-	No obvious systematic relationship

TABLE 7-38 (CONTINUED)

Road Characteristics	Contingency Coefficient	Status for: High Injury Rate	Status for: Low Injury Rate	Comments
Degree of Curvature: - Left Curves	0.09 (NS)	4 to 8 degrees	12 degrees or more	
Weather	0.08 (S)	Fog, Clear	Snow	Aside from fog, effects were due to associated road conditions.
Vertical Alignment	0.06 (S)	Vertical curves	Level	Tangent grades had intermediate rates.
Horizontal Alignment	0.05 (S)	Left curves	Tangent	No significant difference between right and left curves.
Lane Width	0.04 (NS)	Extreme widths	8.5 to 16.5 feet	
Light Conditions	0.04 (NS)	Night	Day	Direct night/day comparison was significant.
Road Division	0.03 (S)	Not divided	Divided	
Number of Lanes	0.03 (S)	Single lane	Double lane	
Grade (Down)	0.03 (NS)	Above 3 degrees	3 degrees or less	
Grade (Up)	0.02 (NS)	Above 3 degrees	3 degrees or less	

TABLE 7-38 (CONTINUED)

On-Road Events and Departure Characteristics	Contingency Coefficient	Status for: High Injury Rate	Status for: Low Injury Rate	Comments
Maneuver	0.11 (S)	No corrective response	Turns	External influence had intermediate rate.
Departure Angle	0.11 (S)	0 to 8 degrees	-	
Distance from Origin to Tire Marks	0.10 (S)	-	26 to 100 feet	
Induced Control Failure	0.09 (S)	No induced control failure	Due to ice or snow	
Departure Attitude	0.07 (S)	Tracking	Not tracking	
Departure Configuration	0.07 (S)	Double departure - both sides	Single departure	
Malfunction	0.06 (S)	-	Vehicle breakdown	
Tire Marks	0.04 (S)	No	Yes	
Departure Point	0.02 (NS)	-	Intersections	Right and left side and median had similar rates.
Roadside Factors				
Pole Offset	0.13 (S)	-	-	Increased rate beyond 18 feet.
Ditch Depth	0.09 (S)	3 feet or more	Less than 3 feet	
Border Offset	0.08 (S)	Above 30 feet	30 feet or less	

TABLE 3-38 (CONTINUED)

Roadside Factors	Contingency Coefficient	Status for: High Injury Rate	Status for: Low Injury Rate	Comments
Terrain Contour at Primary Impact	0.08 (S)	Downslope	Shoulder	
Height of Fill	0.07 (NS)	-	-	Rate increased with height
Shoulder Width	0.06 (NS)	5 to 8 feet	9 feet or more	
Ditch Slope	0.06 (NS)	-	-	No clear relationship.
Roadside Culture	0.05 (S)	Rocks, high grass	Light tree growth	
Fill Slope	0.04 (NS)	2:1 or steeper	3:1 or flatter	
Road Class	0.04 (NS)	Rock cut, hill-side	-	
Terrain	0.03 (NS)	Mountainous	-	
Impact Characteristics				
Impact Behavior	0.29 (S)	Compound roll, rollover $\geq 360°$	Through and over, continue	Very high fatality rate for compound roll, and rollover $> 360°$
Object Struck	0.28 (S)	B/O Entrance, tree, field ap-proach	Small sign post, fence, guardrail, trees and brush	
Impact Speed	0.22 (S)	-	-	Increasing injury and fatality rate with speed.
Area of Damage (Nonrollovers)	0.15 (S)	Front	Else	

TABLE 3-38 (CONTINUED)

Miscellaneous	Contingency Coefficient	Status for: High Injury Rate	Status for: Low Injury Rate	Comments
Ejection	0.39 (S)	Ejected	Not Ejected	Extreme fatality rate if ejected.
Restraint Use	0.12 (S)	Not Restrained	Restrained	

It should be noted that the contingency coefficient is influenced by the number of observations. For some purposes, the reader may be interested in effects unweighted by frequency. For example, roadside culture had a low contingency coefficient (0.05), but there were 130 accidents with a rocky roadside which had an injury rate of 66.2 percent, and there were 213 accidents in the presence of light tree growth with a rate of 49.3 percent. Because the number of such accidents was low, rock as a roadside culture was not a major problem. On the other hand, if one had a choice of placing a road on a rocky terrain or on land with light tree growth, he would want to consider the injury rate differential of 17 percent. For such considerations, the reader is best directed to the individual tables.

On the basis of discussions with the Contract Technical Manager, it was decided to conduct further analyses for the effects of ditch depth, border offset, horizontal alignment (direction of curve), and degree of horizontal curvature. The results are given in the Special Studies Section which follows.

8. SPECIAL STUDIES

This section contains some detailed analyses of selected topics. The first four involve the further study of the effects upon injury of ditch depth, border offset, horizontal alignment, and degree of curvature. The strategy was to relate these factors to impact characteristics and then to injury. The section of horizontal alignment includes a separate analysis of vehicles "missing curves".

The next section treats guardrails with regard to impact angle and impact behavior. Following that is a general study of extent of vehicle damage. Next is an examination of ditches directing vehicles toward culverts and a study involving the use of specially collected exposure data to examine ADT effects. Finally, a discussion of countermeasures and their costs is given.

8.1 Depth of Ditch

This set of analyses focuses on the effect of ditch depth on the severest occupant injury. The analytical strategy was to examine the effects of ditch depth on impact characteristics and then, in turn, to determine how much of the ditch effect on injury was accounted for by these impact characteristics.

The specific impact characteristics used were impact speed, impact behavior, and for nonrollover impacts, area of damage and object struck. While it would have been desirable to study the intermediating effects of these impact characteristics jointly, this was precluded by time constraints. Hence each impact characteristic was evaluated singly. As before, the analyses focused upon the primary impact.

Clearly, it can be expected that ditches may influence the likelihood of injury even when the ditch was not involved in the primary impact. For example, passage through a ditch can influence the vehicle's ensuing path and speed; furthermore, ditch depth may influence the driver's response to it.

For these reasons, the accidents discussed here are all those occurring on ditch cut roads, and not just those where the ditch was impacted, or even contacted at all. Thus, the results pertain to the effect of ditch depth on all accidents on ditch cut roads.

Table 8-1 shows the relationship between injury and the depth of roadside ditches. The table contains the same data presented earlier in Section 7. While the results do not show a consistent increase in the injury rate as depth increased, the rate was clearly lower for shallow ditches (one and two feet) than for deep ones (three feet or more); the results in the lower portion of the table reflect this grouping.

TABLE 8-1 SEVEREST INJURY BY DEPTH OF DITCH

	Injury			Total	Injured		% Killed
Depth (ft.)	None	Nonfatal	Fatal		N	%	
1	189	206	16	411	222	54.0	3.9
2	307	324	35	666	359	53.9	5.3
3	140	237	17	394	254	64.5	4.5
4-5	180	221	19	420	240	57.1	4.2
6+	44	66	6	116	72	62.1	5.2
Total	860	1,054	93	2,007	1,147	57.1	4.6
- Depth Grouped -							
1-2	496	530	51	1,077	581	53.9	4.7
3+	364	524	42	930	566	60.9	4.5

In order to explore reasons for the higher rate for the deeper ditches, differences in impact speed, behavior, area, and object struck were compared for shallow and deep ditches. The distributions of impact speeds

for the two conditions are shown in Table 8-2; their difference was statistically significant (X^2_6 = 14.99). The only notable effect was associated with the first speed interval; viz., there were fewer such low speed impacts for the deeper ditches. In other words, among those accidents which occurred in the presence of the shallow ditches, 88 percent of the vehicles had primary impact speeds in excess of 10 MPH, whereas for deeper ditches the figure was 92 percent.

TABLE 8-2 IMPACT SPEED FOR SHALLOW AND DEEP DITCHES

	Shallow Ditches		Deep Ditches	
Speed (MPH)	N	%	N	%
0 - 10	124	11.6	75	8.2
11 - 20	255	23.9	241	26.5
21 - 30	389	36.5	330	36.3
31 - 40	191	17.9	160	17.6
41 - 50	75	7.0	80	8.8
51 - 60	21	2.0	22	2.4
61+	12	1.1	2	0.2
Total	1,067	100.0	910	100.0
- Speed Grouped -				
0 - 10	124	11.6	75	8.2
11+	943	88.4	835	91.8

It was desirable to determine whether this relatively small difference in impact speeds could account for the injury effects associated with ditch depth. This was done in Table 8-3. The first column gives the injury rate for impact speeds above and below 10 MPH; these results were based on primary

TABLE 8-3 IMPACT SPEED AS AN EXPLANATORY FACTOR FOR THE EFFECT OF DITCH DEPTH ON INJURY

		Shallow Ditches		Deep Ditches		
Speed	% Injured	% in Speed Range	Product	% in Speed Range	Product	Injury Rate Differential(%)
10 MPH, or less	41.7	11.6	4.8	8.2	3.8	
Greater than 10 MPH	58.9	88.4	52.1	91.8	54.1	
Estimated Rate (Sum)			56.9		57.5	0.6
Observed Rate			53.9		61.0	7.1

Rate Differential Associated with Speed: 0.6/7.0 = 8.6%

impacts in accidents occurring in the presence of ditches with known depth.* The second column shows the proportion of vehicles in each speed range for shallow ditches; these were obtained from the previous table. The third column gives an estimate of the percentage of vehicles which had injuries and which were in the specified speed range. Thus, the total of these third column entries is the estimated injury rate for shallow ditches. It is the rate which would have occurred if the only difference between accidents in the presence of shallow and deep ditches were impact speed.** Columns four and five reflect the same procedure applied to the deeper ditches. Finally, the last column gives the difference in estimated injury rates for deep versus shallow ditches.

If the severity of accidents occurring in the presence of shallow ditches were wholly attributable to speed of the primary impact, the injury rate would have been 56.9 percent; for the deeper ditches, the rate would have been 57.5 percent. Thus, the rates would have been 0.6 percent higher

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*These injury rates were calculated separately for each analysis. For example, for the impact speed analysis, only those accidents with known primary impact speeds were included. In the impact behavior analysis, only accidents with known primary impact behaviors were included. For this reason, the observed rates may differ somewhat from table to table. The analyses of object struck and impact behavior were likely to have considerably different observed rates since they included only nonrollover impacts.

**Let I denote at least one injury, Sh denote an accident in the presence of a shallow ditch, and S = impact speed. Then, the probability of at least one injury in a shallow ditch accident is given by:

$$P\ (I\,|\,Sh) = \sum_S P\ (I, S\,|\,Sh)$$

$$= \sum_S P\ (I\,|\,S, Sh)\ P\ (S\,|\,Sh)$$

The assumption is made that $P\ (I\,|\,S,Sh)$ equals $P\ (I\,|\,S)$; that is, the injury rate, given ditch depth and speed, depends only on speed. Then,

$$P\ (I\,|\,Sh) = \sum_S P\ (I\,|\,S)\ P\ (S\,|\,Sh).$$

for deep ditches. In comparison, the actual rate differential was 7.0 percent.* Thus, the higher impact speeds for the deeper ditches accounted for only nine percent (0.6/7.0 = 8.6%) of the actual increase in injury rate.

Thus, although deeper ditches had significantly more impacts above 10 MPH, the difference was not large, and, as a result, only a small portion of the increase in injury rate could have been attributed to this factor.

Next, the effects of impact behavior were studied. Table 8-4 shows the distributions of these behaviors for shallow and deep ditches. While there were more rollovers associated with deep ditches than shallow ones, the overall effect of depth on behavior was not statistically significant (X_6^2 = 9.95, with "Other" deleted). Furthermore, the difference in rollovers was primarily due to rollovers of less than 360 degrees. Since these events had previously been shown to have only moderate injury rates, they could not provide an explanation for the greater hazard of deep ditches.

TABLE 8-4 IMPACT BEHAVIOR FOR SHALLOW AND DEEP DITCHES

	Shallow Ditch		Deep Ditch	
Behavior	N	%	N	%
Rollover:				
< 360°	248	23.1	242	26.1
360°	106	9.9	106	11.4
> 360°	63	5.9	60	6.5
Compound	35	3.3	25	2.7
Total	452	42.0	433	46.8
Nonroll Impacts:				
Stop	235	21.9	166	17.9
Thru or Over	42	3.9	25	2.7
Continue	342	31.8	299	32.3
Other	4	0.4	3	0.3
Total	623	58.0	493	53.2
Total	1,075	100.0	926	100.0

*This value was based on the observed rates given at the bottom of the table; they differ somewhat from those in Table 8-1 because they were derived from the more limited data set where impact speed was known.

Next, the effects of object struck on injury were examined for shallow and deep ditches. Table 8-5 gives the distribution of objects struck for the two conditions. The two distributions were found to be significantly different (X^2_{11} = 73.76, after deleting the last two rows due to low expected values). It can be seen that accidents in the presence of deep ditches more often involved primary impacts with ditches, field approaches, and culverts; they less often involved primary impacts with embankments, wooden utility poles, trees, and fences. The overrepresentation of ditch impacts for deeper ditches was to be expected. That field approaches were overrepresented for deeper ditch accidents is reasonable because a field approach, being a raised driveway crossing the ditch, becomes more of an obstacle as ditch depth increases. The increased likelihood of culvert strikes may reflect greater exposure to culverts in presence of deeper ditches; it may also suggest the probability of being directed toward a culvert increases with the depth of the ditch.

TABLE 8-5 OBJECT STRUCK FOR DEEP AND SHALLOW DITCHES

	Shallow Ditch		Deep Ditch	
Object	N	%	N	%
Ditch	65	11.5	97	22.2
Embankment	114	20.2	61	14.0
Field Approach	6	1.1	19	4.4
Culvert	45	8.0	65	14.9
Ground	11	2.0	15	3.4
Small Sign Post	10	1.8	8	1.8
Wooden Utility Pole	98	17.4	39	8.9
Tree	107	19.0	60	13.8
Trees, Brush	24	4.3	19	4.4
Rock(s)	11	2.0	7	1.6
Fence	63	11.2	26	6.0
Guardrail	8	1.4	13	3.0
B/O - Siderail	0	0.0	2	0.5
B/O - Entrance	1	0.2	5	1.1
Total	563	100.0	436	100.0

Continuing the analysis, the object struck proportions were multiplied by their associated injury rates for accidents in the presence of ditches, and the products were summed to give estimated injury rates. The results, given in Table 8-6, show a predicted 2.2 percent increase in injury rate for deep ditches due to the nature of the object struck in the primary impact. This can be compared to an overall injury rate differential for deep versus shallow ditches of 11.6 percent.* Thus, the objects struck accounted for 19 percent of the increase in injury rate of deep ditches.

Because the object struck was a ditch approximately twice as often if the ditch was deep (cf. Table 8-5), a separate analysis was run for these impacts. That is, while the previous analyses pertained to accidents in the presence of a ditch, this analysis applies to nonroll impacts with the ditch itself. The results are given in Table 8-7. While the likelihood of an injury was 36.9 percent for shallow ditches, it was 59.8 percent for deep ones; this was statistically significant ($X_1^2 = 8.14$).

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*As noted earlier, the object struck table is based on nonrollover impacts; hence, the observed injury rates also reflect this subset.

TABLE 8-6 OBJECT STRUCK AS AN EXPLANATORY FACTOR FOR THE EFFECT OF DITCH DEPTH ON INJURY

Object	% Injured	Shallow Ditches % in Object Class	Shallow Ditches Product	Deep Ditches % in Object Class	Deep Ditches Product	Injury Rate Differential (%)
Ditch	50.6	11.5	5.8	22.2	11.2	
Embankment	54.9	20.2	11.1	14.0	7.7	
Field Approach	76.0	1.1	0.8	4.4	3.3	
Culvert	63.6	8.0	5.1	14.9	9.5	
Ground	46.2	2.0	0.9	3.4	1.6	
Small Sign Post	27.8	1.8	0.5	1.8	0.5	
Wooden Utility Utility Pole	54.0	17.4	9.4	8.9	4.8	
Tree	68.9	19.0	13.1	13.8	9.5	
Trees, Brush	41.9	4.3	1.8	4.4	1.8	
Rock(s)	33.3	2.0	0.7	1.6	0.5	
Fence	16.9	11.2	1.9	6.0	1.0	
Guardrail	33.3	1.4	0.5	3.0	1.0	
B/O - Siderail	100.0	0.0	0.0	0.5	0.5	
B/O - Entrance	83.3	0.2	0.2	1.1	0.9	
Estimated Rate (Sum)			51.7		53.9	2.2
Observed Rate			47.6		59.2	11.6

Rate Differential Associated with Object Struck: 2.2/11.6 = 19.0%

TABLE 8-7 SEVEREST INJURY BY DEPTH OF DITCH IN NONROLLOVER DITCH IMPACTS

	Injury			Total	Injured		% Fatal
Depth (ft.)	None	Nonfatal	Fatal		N	%	
2 or less	41	24	0	65	24	36.9	0.0
3 or more	39	57	1	97	58	59.8	1.0
Total	80	81	1	162	82	50.6	0.6

Similarly, the effects of ditch height of nonroll impacts with field approaches and culverts were also examined. In neither instance was the likelihood of injury significantly higher in the presence of deep ditches. For field approaches just the opposite was true, but the limited number of observations precluded a significant difference. For culverts, the injury rate differed by one percent for shallow and deep ditches. Thus, the effect of deep ditches was to increase the frequency of colliding with field approaches and culverts, but not to increase the severity of these impacts. Regarding collision with ditches themselves, the ditches over two feet deep were both (1) struck relatively more often, and (2) conducive to a greater likelihood of injury.

Table 8-8 gives the distributions of area of impact for accidents in the presence of shallow and deep ditches. The distributions were significantly different (X_4^2 = 12.53, with top impacts deleted); the major effect was an underrepresentation of frontal impacts and an overrepresentation of undercarriage impacts among the deep ditch accidents. However, because frontal impacts were known to be more severe than were impacts to other areas, impact area could not possibly help to explain the higher impact rate for deep ditch accidents.

TABLE 8-8 IMPACT AREA FOR SHALLOW AND DEEP DITCHES

	Shallow Ditch		Deep Ditch	
Area	N	%	N	%
Front	393	63.4	283	58.0
Right	91	14.7	72	14.8
Back	15	2.4	17	3.5
Left	68	11.0	50	10.2
Top	7	1.1	0	0.0
Undercarriage	46	7.4	66	13.5
Total	620	100.0	488	100.0

On the basis of these analyses, the major factor accounting for the higher injury rate for the deeper ditches (over two feet) was the object struck. Overall, the differences in object struck accounted for 19 percent of the observed injury rate differential for shallow and deep ditches involving nonrollover impacts. Accidents in the presence of deep ditches were more likely to involve impacts with ditches, field approaches, and culverts. Both culverts and field approaches had high injury rates irrespective of ditch depth. The injury rate for impacts with deep ditches was over 20 percent higher than that for shallow ditches.

Primary impact speeds were somewhat higher for accidents in the presence of deep ditches; the reasons for this were unknown. This difference accounted for only nine percent of the difference in the observed injury rates.

8.2 Border Offset

Table 8-9 shows that as border offset increased, so did the likelihood of injury. Since increased offset is generally viewed as a safety measure, this relationship was chosen for more detailed study. The major effect was a higher injury rate for offsets greater than 30 feet, and the data were grouped accordingly.

TABLE 8-9 SEVEREST INJURY BY BORDER OFFSET

	Injury			Total	Injured		% Killed
Offset (ft.)	None	Nonfatal	Fatal		N	%	
0 - 10	436	452	33	921	485	52.7	3.6
11 - 20	376	448	41	865	489	56.5	4.7
21 - 30	220	235	21	476	256	53.8	4.4
31 - 40	97	133	19	249	152	61.0	7.6
41 - 60	88	121	12	221	133	60.2	5.4
61 - 100	51	56	6	113	62	54.9	5.3
101+	194	294	29	517	323	62.5	5.6
Total	1,462	1,739	161	3,362	1,900	56.5	4.8
- Offset Grouped -							
0 - 30	1,032	1,135	95	2,262	1,230	54.4	4.2
30+	430	604	66	1,100	670	60.9	6.0

All four of the impact characteristics were significantly related to border offset. The first, impact speed, is shown in Table 8-10 ($X^2_6 = 32.32$). The results show that the impact speeds below 20 MPH were overrepresented among primary impacts in the presence of the smaller offsets. The data were grouped for speeds above and below 20 MPH, and estimates for speed effects derived. The results are in Table 8-11.

TABLE 8-10 IMPACT SPEED BY BORDER OFFSET

	Border Offset (ft.)			
	0 - 30		31+	
Speed (MPH)	N	%	N	%
0 - 10	238	10.7	78	7.3
11 - 20	611	27.6	232	21.6
21 - 30	776	35.0	424	39.4
31 - 40	355	16.0	190	17.7
41 - 50	160	7.2	108	10.0
51 - 60	54	2.4	32	3.0
61+	21	0.9	11	1.0
Total	2,215	100.0	1,075	100.0
	- Speed Grouped -			
0 - 21	849	38.3	310	28.8
21+	1,366	61.7	765	71.2

TABLE 8-11 IMPACT SPEED AS AN EXPLANATORY FACTOR FOR THE EFFECT OF BORDER OFFSET ON INJURY RATES

		Small Offset		Large Offset		
Speed (MPH)	% Injured	% in Speed Range	Product	% in Speed Range	Product	Injury Rate Differential (%)
20 or less	47.2	38.3	18.1	28.8	13.6	
Above 20	62.2	61.7	38.4	71.2	44.3	
Estimated Rate (Sum)			56.5		57.9	1.4
Observed Rate			54.8		61.2	6.4

Rate Differential Associated with Speed: 1.4/6.4 = 21.9%

As indicated, if impact speed differences were the only reasons for the border offset effects, one would expect injury rates of 56.5 and 57.9 percent, for small and large offsets respectively. The actual corresponding rates were 54.8 and 51.2 percent. Thus, 22 percent of the difference in the actual rates was associated with the difference in impact speeds.

In an earlier section of this report, data were presented suggesting that travel speeds increased with border offset. This, combined with the above results, imply that improved enforcement of travel speeds may be needed on roads with border offsets in excess of 30 feet, and that such enforcement could be expected to reduce the likelihood of injury in single vehicle accidents.

Table 8-12 shows considerable differences in impact behaviors for large and small offsets ($X_7^2 = 129.10$). The largest single contribution to this was the higher likelihood of rollovers associated with large offsets ($X_1^2 = 94.36$).

The effect of this difference upon injury rates was documented in Table 8-13. These results show that over 50 percent of the increase in the injury rate for large offsets was associated with the greater likelihood of rolling over.

TABLE 8-12 IMPACT BEHAVIOR BY BORDER OFFSET

Behavior	Border Offset (ft.) 0 - 30 N	0 - 30 %	31+ N	31+ %
Rollover:				
< 360°	487	21.6	288	26.2
360°	170	7.5	163	14.8
> 360°	104	4.6	110	10.0
Compound	68	3.0	37	3.4
Total	829	36.7	598	54.4
Nonroll Impact:				
Stop	520	23.0	181	16.5
Thru or Over	72	3.2	37	3.4
Continue	826	36.6	274	24.9
Other	9	0.4	9	0.8
Total	1,427	63.3	501	45.6
Total	2,256	100.0	1,099	100.0

TABLE 8-13 IMPACT BEHAVIOR AS AN EXPLANATORY FACTOR FOR THE EFFECT OF BORDER OFFSET ON INJURY RATES

Behavior	% Injured	Small Offset: % in Behavior Class	Small Offset: Product	Large Offset: % in Behavior Class	Large Offset: Product	Injury Rate Differential (%)
Rollover	67.5	36.7	24.8	54.4	36.7	
Nonroll Impact	48.3	63.3	30.6	45.6	22.0	
Estimated Rate (Sum)			55.3		58.7	3.4
Observed Rate			54.3		60.9	6.6

Rate Differential Associated with Behaviors: 3.4/6.6 = 51.5%

The next two tables, 8-14 and 8-15, show the relationship between border offset and object struck, and the influence of that association on injury. As mentioned earlier, only nonrollover accidents were included in the object struck analyses. The second of the two tables shows that for such accidents, the effect of border offset on injury rate was quite small; the observed rate was only 1.6 percent higher for the larger offsets. A chi-square test of this differential was not statistically significant ($X_1^2 = 0.33$). Thus, while the overall injury rates for large and small offsets were different, this was wholly due to rollovers and not nonrollover impacts. None the less, it was decided to continue the analysis of nonroll impacts. First, there was some interest in determining if there were significant associations between offset and object struck and between offset and impact area. Second, there was interest in determining the role of object struck and impact area on the offset/injury relationship within the samples of nonroll impact accidents, even if there was no generalizeable difference between them.

Returning to the first of the two tables, it can be seen that field approaches, ground impacts, and fences were overrepresented among the large offsets, while embankments and guardrails were underrepresented. Thus, the large offset situations seemed to more often reflect the characteristics of open farm land. In any case, the distributions of objects struck were significantly different for small versus large offsets (X^2_{13} = 143.08). Utilizing this information and the injury rates for nonroll impacts with the listed objects, estimated rates for small and large offsets were 49.7 and 51.2 percent, respectively. The difference of 1.5 percent was almost equal to the observed difference of 1.6 percent, so that over 90 percent of the observed offset effect on injury rates for nonroll impacts was accounted for by the nature of the object struck.

TABLE 8-14 OBJECT STRUCK BY BORDER OFFSET

	Border Offset (ft.)			
	0 - 30		31+	
Object	N	%	N	%
Ditch	136	10.2	41	9.8
Embankment	245	18.3	31	7.4
Field Approach	14	1.0	21	5.0
Culvert	59	4.4	25	6.0
Ground	20	1.5	27	6.5
Small Sign Post	20	1.5	12	2.9
Wooden Utility Pole	139	10.4	56	13.4
Tree	264	19.7	90	21.6
Trees, Brush	132	9.9	49	11.8
Rock(s)	36	2.7	7	1.7
Fence	40	3.0	33	7.9
Guardrail	172	12.9	14	3.4
B/O - Side Rail	38	2.8	2	0.5
B/O - Entrance	23	1.7	9	2.2
Total	1,338	100.0	417	100.0

TABLE 8-15 OBJECT STRUCK AS AN EXPLANATORY FACTOR FOR THE EFFECT OF BORDER OFFSET ON INJURY RATES

		Small Offset		Large Offset		
Object	% Injured	% in Object Class	Product	% in Object Class	Product	Injury Rate Differential (%)
Ditch	44.6	10.2	4.5	9.8	4.4	
Embankment	52.9	18.3	9.7	7.4	3.9	
Field Approach	71.4	1.0	0.7	5.0	3.6	
Culvert	67.9	4.4	3.0	6.0	4.1	
Ground	44.7	1.5	0.7	6.5	2.9	
Small Sign Post	18.8	1.5	0.3	2.9	0.5	
Wooden Utility Pole	51.3	10.4	5.3	13.4	6.9	
Tree	68.1	19.7	13.4	21.6	14.7	
Trees, Brush	40.9	9.9	4.0	11.8	4.8	
Rock(s)	41.9	2.7	1.1	1.7	0.7	
Fence	26.0	3.0	0.8	7.9	2.1	
Guardrail	29.0	12.9	3.7	3.4	1.0	
B/O - Side Rail	47.5	2.8	1.3	0.5	0.2	
B/O - Entrance	62.5	1.7	1.1	2.2	1.4	
Estimated Rate (Sum)			49.7		51.2	1.5
Observed Rate			49.7		51.3	1.6

Rate Differential Associated with Objects: 1.5/1.6 = 93.8%

The relationship between area of impact and border offset is shown in Table 8-16. The differences between large and small offsets was statistically significant ($X_5^2 = 22.21$), and was largely due to the overrepresentation of frontal impacts for the smaller offsets ($X_1^2 = 15.52$). Apparently, as vehicles were allowed to travel further to nonrollover primary impacts, the likelihood of tracking just before impact decreased.

TABLE 8-16 IMPACT AREA BY BORDER OFFSET

Area	Border Offset (ft.) 0 - 30 N	0 - 30 %	31+ N	31+ %
Front	893	63.2	260	53.1
Right	179	12.7	82	16.7
Back	39	2.8	28	5.7
Left	174	12.3	63	12.9
Top	11	0.8	6	1.2
Undercarriage	118	8.3	51	10.4
Total	1,414	100.0	490	100.0
- Area Grouped -				
Front	893	63.2	260	53.1
Else	521	36.8	230	46.9

Since frontal impacts tend to be more severe than do other nonrollover impacts, these data suggest the effect of impact area would be to yield a higher injury rate for small offsets; as such impact area could not possibly account for the higher rate associated with large offsets. In order to document this, the analysis was continued and the results are presented in Table 8-17. That the resultant estimated injury rate differential was negative confirms the expected effect.

TABLE 8-17 AREA OF DAMAGE AS AN EXPLANATORY FACTOR FOR THE EFFECT OF BORDER OFFSET ON INJURY RATES

		Small Offset		Large Offset		
Area	% Injured	% in Area Class	Product	% in Area Class	Product	Injury Rate Differential (%)
Front	53.9	63.2	34.1	53.1	28.6	
Else	40.6	36.8	14.9	46.9	19.0	
Estimated Rate (Sum)			49.0		47.7	-1.3

In summary, injury rates were higher for accidents in the presence of large border offsets. Almost one-fourth of this effect was associated with higher primary impact speeds among the large offset accidents. This, in turn, was previously attributed to higher travel speeds on roads with large offsets.

Over one-half of the higher injury rate was associated with the greater likelihood of rollovers for large offsets. It would, however, be quite inappropriate to conclude the impact speed and impact behavior, taken together, accounted for three-fourths of the observed injury rate differential. This is because impact speed and impact behavior were correlated. For example, the extent of rollover could be expected to increase with speed. In order to clarify the combined role of impact speed and behavior, the analysis of border offset could be repeated for the two variables taken jointly. While such analyses were thought to be of interest, they were not of such a priority as to preempt other analyses.

Regarding nonrollover impacts, the results showed almost all of the large offset effect was due to differences in the objects struck. Field approaches, ground impacts, and fences were overrepresented, and embankments and guardrails were underrepresented among accidents in the presence of large offsets. However, the difference in injury rates between large and small offsets for nonrollover impacts was so small as to preclude statistical significance.

Thus, the greater likelihood of rollovers and higher impact speeds for large offset accidents were major factors in accounting for their higher injury rate. Considering only nonroll impacts, there was very little injury rate difference between the two offset conditions.

8.3 Horizontal Alignment*

Although the effects of horizontal alignment were not large, it was thought that the topic was of sufficient general interest to be given further study. Table 8-18 shows the injury rate was highest for left curves and lowest for straight roads with right curves similar to the latter.

TABLE 8-18 SEVEREST INJURY BY HORIZONTAL ALIGNMENT

Alignment	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Tangent	2,008	2,259	203	4,470	2,462	55.1	4.5
Left Curve	715	1,017	107	1,839	1,124	61.1	5.8
Right Curve	523	652	64	1,239	716	57.8	5.2
TOTAL	3,246	3,928	374	7,548	4,302	57.0	5.0

In Table 8-19, the analysis was repeated with alignment crossed with departure point. First, it shows there was little difference in the injury rates for left and right departures on tangents. In contrast, there was a quite notable interaction between departure point and direction of curve. The two lowest injury rates were obtained for left departures on left curves and right departures on right curves; hence, the highest rates occurred on right departures from left curves and left departures from right curves. That is, the injury rate was higher for vehicles departing the outside of a curve (e.g., right departure on left curve) than for vehicle departing the inside (e.g., right departure on right curve). This is shown explicitly in Table 8-20. Note that whereas the injury rate differed by three percent for left curves versus right, it differed by ten percent for inside versus outside departures. Thus, the departure type (inside-outside) was the more dominant factor. On this basis, the higher injury rate for left curves was due to the larger proportion of

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* This section treats the effects of left and right curves on injury. Degree of curvature is examined in the following section.

-19 SEVEREST OCCUPANT INJURY BY HORIZONTAL ALIGNMENT AND DEPARTURE POINT

Alignment	Dep. Point	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
Tangent	Right	1,202	1,369	134	2,705	1,503	55.6	5.0
	Left	727	798	67	1,592	865	54.3	4.2
Left Curve	Right	551	823	88	1,462	911	62.3	6.0
	Left	161	183	17	361	200	55.4	4.7
Right Curve	Right	252	241	19	512	260	50.8	3.7
	Left	263	405	45	713	450	63.1	6.3
TOTAL		3,156	3,819	370	7,345	4,189	57.0	5.0

TABLE 8-20 SEVEREST INJURY BY DEPARTURE TYPE

Type	Injury None	Injury Nonfatal	Injury Fatal	Total	Injured N	Injured %	% Killed
Outside	814	1,228	133	2,175	1,361	62.6	6.1
Inside	413	424	36	873	460	52.7	4.1
TOTAL	1,227	1,652	169	3,048	1,821	59.7	5.5

outside departures. Using the data in Table 8-19, there were 1,462/(1,462 + 361) = 80.2 percent outside departures for left curves; for right curves, there were only 713/(713 + 512) = 58.2 percent.

In summary, the injury rate was higher for vehicles continuing "straight" off curves as compared to those which were turned too far. The former group, or outside departures, constituted a larger portion of left curve departures than right curve departures; thus, the higher injury rate on left curves.

Because departure type was an important factor in the determination of injury rates on curves, it was studied in terms of the impact characteristics to better understand the mechanisms involved. Table 8-21 shows that the impact speeds were different for the two departure types (X^2_6 = 14.68). The major difference was the higher likelihood of impacts in the 11 to 20 MPH range for inside departures. Because there was little difference in the 0 to 10 MPH range, the first two intervals were grouped together. The lower portion of the table shows there were five percent more low speed (0-20 MPH) impacts for inside departures.

It is likely that the outside departures had higher speeds for several reasons. First, if a vehicle enters a curve at an excessive speed, it is likely to lose the ability to follow the curve and even more likely to be unable to turn too far. Second, if a driver fails to respond to a curve, concommitantly deriving no on-road deceleration, he will depart the outside of the curve. Third, the driver has the least on-road deceleration space when he departs the right side of a left curve. As shown earlier, this type of departure constitutes a very large portion of the outside departures. It is well to note, however, despite these reasons for higher speeds in outside departures, the impact speeds did not differ by a large amount for the two departure types.

TABLE 8-21 IMPACT SPEED BY DEPARTURE TYPE

Speed (MPH)	Inside N	Inside %	Outside N	Outside %
0-10	62	7.4	169	8.0
11-20	226	26.9	456	21.5
21-30	307	36.5	776	36.6
31-40	155	18.4	440	20.7
41-50	61	7.3	196	9.2
51-60	26	3.1	62	2.9
61+	4	0.5	23	1.1
TOTAL	841	100.0	2,122	100.0
- Speed Grouped -				
0-20	288	34.2	625	29.5
21+	553	65.8	1,497	70.5

Table 8-22 shows that the effect of the differential impact speeds on injury rates was not large. The estimated injury rate differential due to impact speed was only 0.9 percent, which accounted for only nine percent of the observed difference in injury rates.

TABLE 8-22 IMPACT SPEED AS AN EXPLANATORY FACTOR FOR THE EFFECT OF DEPARTURE TYPE AND INJURY

Speed (MPH)	% Injured	Inside Departure: % in Speed Range	Inside Departure: Product	Outside Departure: % in Speed Range	Outside Departure: Product	Differential (%)
0-20	47.0	34.2	16.1	29.5	13.9	
21+	65.8	65.8	43.3	70.5	46.4	
Estimated Rate (Sum)			59.4		60.3	0.9
Observed Rate			53.0		62.7	9.7

Rate Differential Associated with Speed: 0.9/9.7 = 9.3%

Impact behaviors for inside and outside departures were tabulated and are shown in Table 8-23. The chi-square showed no significant difference (X_6^2 = 10.36, with "Other" deleted), and no further analyses were conducted with this variable.

TABLE 8-23 IMPACT BEHAVIOR BY DEPARTURE TYPE

Behavior	Inside Departure N	Inside Departure %	Outside Departure N	Outside Departure %
Rollover:				
< 360°	218	25.1	475	21.9
360°	95	10.9	254	11.7
> 360°	80	9.2	215	9.9
Compound	26	3.0	87	4.0
Total	419	48.2	1,031	47.5
Nonroll Impact:				
Stop	138	15.9	415	19.0
Thru or Over	33	3.8	86	4.0
Continue	275	31.6	627	28.9
Other	4	0.5	11	0.5
Total	450	51.8	1,139	52.5
TOTAL	869	100.0	2,170	100.0

Table 8-24 gives the objects struck; the difference between inside and outside departures was significant (X_{12}^2 = 34.47, with the last two rows combined). The outside departures had higher relative frequencies for trees and, to a lesser extent, wooden utility poles; they had fewer impacts with embankments and guardrails. The reasons for these differences are unknown, but one consideration can be offered regarding guardrails. If a large natural obstacle lies in the desired path of a road, the road will be constructed to go around the obstacle which will then reside on the inside of the curve.

(Note that the inside of a curve is the same regardless of the direction of travel.) This suggests the opportunity to strike a guardrail may be greater for inside departures. The same reasoning may apply to embankments.

TABLE 8-24 OBJECT STRUCK BY DEPARTURE TYPE

	Inside Departure		Outside Departure	
Object	N	%	N	%
Ditch	37	9.6	100	9.8
Embankment	66	17.1	117	11.5
Field Approach	4	1.0	23	2.3
Culvert	19	4.9	61	6.0
Ground	14	3.6	43	4.2
Small Sign Post	8	2.1	22	2.2
Wooden Utility Pole	49	12.7	156	15.3
Tree	61	15.8	208	20.4
Trees, Brush	27	7.0	84	8.3
Rock(s)	11	2.8	32	3.1
Fence	31	8.0	96	9.4
Guardrail	46	11.9	56	5.5
B/O - Side Rail	10	2.6	10	1.0
B/O - Entrance	4	1.0	10	1.0
TOTAL	387	100.0	1,018	100.0

Whatever the reasons for the differences in object struck, their effect on injury rates is shown in Table 8-25. The estimated difference due to objects struck was 1.7 percent; this constitutes 17 percent of the observed difference in inside versus outside departures for nonrollover impacts. Examination of the products in Table 8-25 shows that the single largest contributor to the greater frequency of outside departures was impacts with trees.

TABLE 8-25 OBJECT TYPE AS AN EXPLANATORY FACTOR FOR THE EFFECT OF DEPARTURE TYPE ON INJURY

Object	% Injured	Inside Departure: % in Object Class	Inside Departure: Product	Outside Departure: % in Object Class	Outside Departure: Product	Injury Rate Differential (%)
Ditch	52.6	9.6	5.0	9.8	5.2	
Embankment	57.9	17.1	9.9	11.5	6.7	
Field Approach	63.0	1.0	0.6	2.3	1.4	
Culvert	71.3	4.9	3.5	6.0	4.3	
Ground	49.1	3.6	1.8	4.2	2.1	
Small Sign Post	16.7	2.1	0.4	2.2	0.4	
Wooden Utility Pole	53.7	12.7	6.8	15.3	8.2	
Tree	71.0	15.8	11.2	20.4	14.5	
Trees, Brush	48.6	7.0	3.4	8.3	4.0	
Rock(s)	51.2	2.8	1.4	3.1	1.6	
Fence	26.8	8.0	2.1	9.4	2.5	
Guardrail	29.4	11.9	3.5	5.5	1.6	
B/O - Side Rail	65.0	2.6	1.7	1.0	0.7	
B/O - Entrance	64.3	1.0	0.6	1.0	0.6	
Estimated Rate (Sum)			52.0		53.7	1.7
Observed Rate			46.0		56.0	10.0

Rate Differential Associated with Object Struck: 1.7/10.0 = 17.0%

The distributions of area of damage for the two departure types is shown in Table 8-26; they were significantly different ($X_5^2 = 13.66$). The areas were grouped as shown in the lower part of the table to simplify the analysis and to increase the low cell frequencies while maintaining most of the useful information in the original tabulation.

TABLE 8-26 AREA OF DAMAGE BY DEPARTURE TYPE

Area	Inside N	Inside %	Outside N	Outside %
Front	246	55.9	686	60.9
Right	78	17.7	181	16.1
Back	17	3.9	17	1.5
Left	54	12.3	132	11.7
Top	2	0.5	17	1.5
Undercarriage	43	9.8	94	8.3
TOTAL	440	100.0	1,127	100.0
- Area Grouped -				
Front	246	55.9	686	60.9
Side	132	30.0	313	27.8
Back	17	3.9	17	1.5
Else	45	10.2	111	9.8

The data show a higher incidence of frontal versus side or rear impacts for outside departures. This is to be expected since inside departures tend to involve turning too far while outside departures involve not turning enough. This is consistent with earlier results (cf. Table 3-7) showing the likelihood of not tracking was higher for inside than outside departures. Table 8-27 shows the effect of these differences. Twelve percent of the observed injury rate differential was accounted for by the impact area.

TABLE 8-27 AREA OF DAMAGE AS AN EXPLANATORY FACTOR FOR THE EFFECT OF DEPARTURE TYPE ON INJURY

		Inside Departure		Outside Departure		
Area	% Injured	% in Area Class	Product	% in Area Class	Product	Injury Rate Differential (%)
Front	58.3	55.9	32.6	60.9	35.5	
Side	40.0	30.0	12.0	27.8	11.1	
Back	23.5	3.9	0.9	1.5	0.4	
Else	45.5	10.2	4.6	9.8	4.5	
Estimated Rate (Sum)			50.1		51.4	1.3
Observed Rate			43.4		54.0	10.6

Rate Differential Associated with Impact Area: 1.3/10.6 = 12.3%

At this point then, it has been shown that the higher injury rate on left curves versus right curves was associated with the larger proportion of outside departures on left curves. In addition, it has been shown that the higher injury rate for outside departures was, in part, due to higher impact speeds, more frontal impacts, and more impacts with trees.

Some additional analyses were run in an attempt to determine factors which might influence the likelihood of inside versus outside departures.* The

* Earlier analyses in Section 2 related some of these factors to straight versus curved roads. The reader should distinguish between those results and the ones presented here which pertain only to accident curves and which draw their implications from departure type.

factors were selected on the basis that outside departures are more likely to occur if the driver fails to observe the curve. The results are presented in Table 8-28.

The first tabulation shows that drinking drivers were apparently less attentive than drivers reported as not drinking in that the drinkers were more likely to have outside departures. The second analyses shows that drivers reported as tired or asleep were more likely to miss the curve rather than overrespond to it. Note that this result may have arisen in part because departing the outside of a curve may have alerted the investigating police officer to the possibility that the driver fell asleep. The third table shows no evidence that the driver's familiarity with the road contributed to differences in departure type.

The next analysis shows a significant interaction between light conditions and departure type. Much of this was due to the greater likelihood of outside departures at night (78.2%) versus that during daytime accidents (67.1%); (X_1^2 = 39.07). Further analysis would be required to determine the extent to which this difference was accounted for by drinking drivers at night.

The next analysis was performed to determine if warning signs would reduce the likelihood of outside departures. While the results were statistically significant, the major effect was fewer outside departures in accidents when no sign was present. This may reflect an insufficiency in the attention-getting value of the signs, or it may simply reflect the placement of signs at the more hazardous locations.

A similar analysis was conducted to study the effect of centerlines. ("Yes - No Passing - Trav." means there was a centerline with no passing in the traveled direction indicated.) While the overall chi-square failed to indicate significance, almost all of the differences in the two data sets was due to centerlines versus no centerlines; this was significant as shown. The results suggest the presence of a centerline was, to some extent, effective in warning drivers of curves.

TABLE 8-28 FACTORS AFFECTING DEPARTURE TYPE

	Inside Departures	Outside Departures	Percent Outside	Chi-Square	Degrees of Freedom	Significant?
Drinking Status						
Not Drinking	454	931	67.2			
Had Been Drinking	93	276	74.8			
Drinking was Contributory	82	235	74.1			
Cited for DWI	77	315	80.4	30.45	3	Yes
	706	1,757				
Driver Condition						
No Problem Reported	256	429	62.6			
Tired	9	29	76.3			
Asleep	47	184	79.7	24.22	2	Yes
	312	642				
Road Familiarity						
Daily	212	518	71.0			
Once or More/Week	180	448	71.3			
Once or More/Month	100	285	74.0			
Rarely	149	375	71.6			
Never Before	92	259	73.8	1.92	4	No
	733	1,885				
Light Condition						
Day	511	1,044	67.1			
Dawn	17	41	70.7			
Dusk	28	37	56.9			
Night: Lighted	13	37	74.0			
Not Lighted	226	822	78.4	46.04	4	Yes
	795	1,981				
Signs						
Curve	109	253	69.9			
Curve W/Speed	46	193	80.8			
Large Arrow	8	52	86.7			
Other	477	1,274	72.8			
None	248	446	64.3	36.38	4	Yes
	888	2,218				

TABLE 8-28 (CONTINUED)

	Inside Departures	Outside Departures	Percent Outside	Chi-Square	Degrees of Freedom	Significant?
Centerlines						
Yes	168	409	70.9			
Yes - No Passing - Opp.	72	181	71.5			
Yes - No Passing - Trav.	66	151	69.6			
Yes - No Passing - Both	241	609	71.6			
None	141	455	76.3	6.49	4	No
	688	1,805				
- Grouped -						
Yes	547	1,350	71.2			
No	141	455	76.3	6.08	1	Yes
Edgelines						
Yes	516	1,111	68.3			
No	305	939	75.5	17.88	1	Yes
	821	2,050				
Right Shoulder Width (ft.) (Left Curves Only)						
0	42	184	81.4			
1-2	38	182	82.7			
3-4	71	406	85.1			
5-6	76	285	78.9			
7-8	43	151	77.8			
9+	64	154	70.6	22.01	5	Yes
	334	1,362				

Another analysis of this type was done to measure the association between departure type and the existence of pavement edgelines. The results were similar to those for centerlines. The likelihood of outside departures versus inside departure was significantly lower when edgelines were present.

The final analysis in this group relates departure type to shoulder width; it applies only to the right shoulder on left curves. (No systematic relationship was found for left shoulders on right curves.) While shoulder width might be a factor in delineating the road edge, the rationale for this analysis was based on the room for driver error created by the shoulder rather than effects upon driver awareness. Since most departures on left curves were on the right side, it was thought that the righthand shoulder might be beneficial. If it were, one would expect the proportion of outside departures to decrease with increasing shoulder width.

The results show that this was indeed true. For shoulders zero to four feet wide, 83.6 percent of the departures were to the right. The proportion dropped to 78.6 and 70.6 percent respectively for shoulders five to eight feet wide and for those nine feet or wider.

In concluding this discussion, two points should be noted. First, the results of the separate analyses are not independent. For example, the higher likelihood of outside departures for drinkers and for tired or sleeping drivers is undoubtedly, in part, due to drinking drivers who were tired or who fell asleep. Similarly, as noted earlier, the greater likelihood of outside departures at night probably resulted in part from the fact that there are more drinkers at night. Note that this in no way diminishes the nighttime problem, but rather points out that it may not be solely associated with lighting.

In a similar way, the effects of centerlines, edgelines, and shoulder width may not have been independent in that the presence or quality of one may have been correlated with that of the others.

The second point is that the effects of centerlines, edgelines, and shoulder width may not reflect the fundamental reasons for fewer outside departures. Rather, it is possible that their apparent benefits may reflect the possibility that pavement markings and wider shoulders are simply associated with roads having less demanding curves. Further analysis of this question is certainly recommended.

In summary, the injury rate for left curves was greater than that for right curves due to the greater likelihood of outside departures on left curves. The greater severity of outside departures was associated with higher impact speeds, more tree impacts, and more frontal impacts. While the reason for the greater frequency of tree impacts was not known, the higher speeds and more frontal impacts are characteristic of the differences in the nature of inside and outside departures.

On the basis of the greater likelihood of outside departures, it seems clear that if an immovable object must be placed near a curve, it would be advisable to place it on the inside of the curve. If that choice is not available, consideration should be given to a protective barrier.

In the final group of analyses, the proportion of curve departures which occurred on the outside of the curve was used as a measure of the driver's lack of awareness of the curve or of an appropriate speed to negotiate it. Results showed that drinking drivers and those reported as tired or asleep more often departed curves on the outside. Road familiarity was not shown to be important in this regard. More outside departures occurred at night than during the day. While curve warning signs were not associated with lower proportions of outside departures, the presence of centerlines and edgelines were. Finally, the presence of shoulders of increasing width was associated with a decreasing proportion of outside departures on left curves, thereby suggesting the shoulders provided a buffer area for accident avoidance.

8.4 Degree of Curvature

Having examined curve direction, it was of interest to study degree of curvature. Earlier analysis did not show a significant effect upon injury (cf. Table 7-14), but did reflect a higher injury rate on left curves which were shallow. Indeed, a direct test of these left curve data comparing the two shallow categories to the two sharper curve categories in terms of fatal plus nonfatal injuries versus no injury was statistically significant (X_1^2 = 5.51). Since there were more accidents on left curves than right, and since the effect of curvature for right curves lacked systematic form*, the following analyses focus on left curves.

Before looking at injury, some background findings are given. Table 8-29 shows that the proportion of accidents in which there were tire marks on the road prior to departure increased markedly with degree of curvature. Since tire marks generally arise from locking the wheels due to braking and/or skidding sidewards due to steering inputs, these data imply that drivers more often responded aggressively to sharp curves. This, in turn, suggests that drivers were more often aware of sharp curves than shallow ones.

TABLE 8-29 TIRE MARKS BY DEGREE OF CURVATURE FOR LEFT CURVES

	Curvature (Degrees)							
	0+ - 4		4+ - 8		8+ - 12		12+	
Tire Marks	N	%	N	%	N	%	N	%
No	504	74.7	227	65.6	99	58.2	62	50.4
Yes	171	25.3	119	34.4	71	41.8	61	49.6
Total	675	100.0	346	100.0	170	100.0	123	100.0

* This was also true of the more detailed analyses which were used to examine the curvature of right curves. This was thought to arise from the previously demonstrated propensity for drivers to turn too little, rather than too much, thereby inducing outside departures. On the right curve, however, the oncoming traffic lane provides a buffer which could well have reduced the effects of degree of curvature in single vehicle accidents.

Table 8-30 gives the distance from the onset of the tire marks (when they occurred) to the point of departure. In contrast to the previous table, these results show that longer tire marks were most often associated with the shallower curves. This can be seen most clearly in the second row where it is shown that the proportion of vehicles with distances 50 feet or less increased from 25.0, to 30.5, to 33.3, to 41.1 percent for the successive, increasingly sharp curves. While this could suggest that the drivers responded earlier to the shallow curves, that would appear to conflict with the previous findings of greater responsiveness to the sharp curves; it is also at odds with what one would expect.

A more satisfying explanation is that as the degree of curvature increased, the room to maneuver prior to departure decreased; hence, the (on-road) tire marks also decreased in length.

Table 8-31 gives the proportion of outside departures as a function of degree of curvature. It can first be noted that, irrespective of the degree of curvature, the proportion of outside departures was quite high. Note that since these data reflect right departures on left curves, the earlier implication of limited maneuvering room is quite appropriate. The table shows that as the degree of curvature increased so did the proportion of vehicles departing the right side of the road. That is, for sharper curves, there were more drivers who provided too little steering input rather than too much.

Finally, Table 8-32 shows that the proportion of vehicles which were tracking at departure decreased with degree of curvature. This is compatible with the greater incidence of tire marks with increasing curvature and suggests a more abrupt deceleration and loss of control in this situation.

TABLE 8-30 DISTANCE FROM ORIGIN OF TIRE MARKS TO DEPARTURE POINT BY DEGREE OF CURVATURE FOR LEFT CURVES

	Curvature (Degrees)											
	0+ - 4			4+ - 8			8+ - 12			12+		
Distance (ft.)	N	%	Cum. %	N	%	Cum. %	N	%	Cum. %	N	%	Cum. %
1 - 25	11	7.9	7.9	8	7.6	7.6	11	16.7	16.7	9	16.1	16.1
26 - 50	24	17.1	25.0	24	22.9	30.5	11	16.7	33.3	14	25.0	41.1
51 - 100	48	34.3	59.3	33	31.4	61.9	20	30.3	63.6	17	30.4	71.4
101 - 250	48	34.3	93.6	33	31.4	93.3	21	31.8	95.5	16	28.6	100.0
251 - 500	9	6.4	100.0	7	6.7	100.0	3	4.5	100.0	0	0.0	100.0
Total	140	100.0		105	100.0		66	100.0		56	100.0	

TABLE 8-31 DEPARTURE TYPE ON LEFT CURVES BY DEGREE OF CURVATURE

Type	Degree of Curvature 0 - 4	4 - 8	8 - 12	12+
Inside	169	59	25	14
Outside	547	307	157	109
Total	716	366	182	123
Percent Outside	76.4	83.9	86.3	88.6

TABLE 8-32 DEPARTURE ATTITUDE ON LEFT CURVES BY DEGREE OF CURVATURE

Attitude	Degree of Curvature 0 - 4	4 - 8	8 - 12	12+
Tracking	460	212	107	71
Not Tracking	152	91	58	38
Total	612	303	165	109
Percent Tracking	75.2	70.0	64.8	65.1

Summarizing these findings, the sharper left curves were characterized by a greater incidence of tire marks and outside departures, fewer vehicles tracking at departure, and for those vehicles leaving tire marks, an onset closer to the departure point. This suggests that drivers more often responded vigorously to the sharper curves, but with insufficient control and road space to avoid the right side of the road.

Table 8-33 gives injury information as a function of degree of curvature. It shows that the injury rate first increased to the four to eight degree range, and then decreased to a minimum for curves exceeding 12 degrees. In order to concentrate on first order effects, the data were grouped to reflect shallow and sharp curves, or curves up through eight degrees and those greater than eight degrees respectively. Note that the shallow curves had the two highest of the four injury rates. The grouped data show the injury rate was seven percent higher on shallow left curves.

TABLE 8-33 SEVEREST INJURY BY DEGREE OF CURVATURE FOR LEFT CURVES

Curvature (Degrees)	Injury			Total	Injured		% Killed
	None	Nonfatal	Fatal		N	%	
0+ - 4	271	400	42	713	442	62.0	5.9
4+ - 8	118	214	27	359	241	67.1	7.5
8+ - 12	71	97	9	177	106	59.9	5.1
12+	61	59	5	125	64	51.2	4.0
Total	521	770	83	1,374	853	62.1	6.0
- Curvature Grouped -							
0 - 9	389	614	69	1,072	683	63.7	6.4
9+	132	156	14	302	170	56.3	4.6

Table 8-34 shows that impact speeds were lower for the sharper curves. Whereas 26 percent of the shallow curve accident vehicles had their primary impacts in the zero to 20 MPH range, the figure was 40 percent for the sharper curves. The difference was statistically significant ($X_1^2 = 22.12$).

TABLE 8-34 IMPACT SPEED BY DEGREE OF CURVATURE FOR LEFT CURVES

Speed (MPH)	Degree of Curvature 0 - 8 N	%	9+ N	%
0 - 20	269	25.9	118	40.0
21+	769	74.1	177	60.0
Total	1,038	100.0	295	100.0

One might have expected this result. Earlier findings had shown a greater incidence of tire marks for the sharper curves; thus, vehicles may have decelerated more often before departing such curves. This explanation is weakened somewhat, however, because the tire marks were initiated closer to the departure point for the sharp curves; therefore, deceleration distance was more limited. A more likely explanation is simply that most drivers are likely to enter a sharp curve more slowly (even if not slow enough) than they would a shallow one. Furthermore, to the extent that sharp curves tend to reflect terrain conducive to winding roads, travel speeds in general are likely to be lower.

Table 8-35 gives the estimated injury rate which would have occurred if the only degree of curvature effects were due to impact speeds. It shows a 2.7 percent higher injury rate for the shallow curves. This constitutes 41 percent of the observed injury rate differential. Thus, to the extent that impact speed reflects travel speed, notable benefits were achieved by increased caution on curves.

TABLE 8-35 IMPACT SPEED AS AN EXPLANATORY FACTOR FOR THE EFFECT OF DEGREE OF CURVATURE ON INJURY

		Degree of Curvature				
		0 - 8		9+		
Speed (MPH)	% Injured	% in Speed Range	Product	% in Speed Range	Product	Injury Rate Differential (%)
0 - 20	48.6	25.9	12.6	40.0	19.4	
21+	67.7	74.1	50.2	60.0	40.6	
Estimated Rate (Sum)			62.8		60.1	2.7
Observed Rate			58.5		51.9	6.6

Rate Differential Associated with Impact Speed: 2.7/6.6 = 40.9%

Impact behavior for the two curve groups is shown in Table 8-36. The interaction of degree of curvature and primary impact behavior was statistically significant (X_6^2 = 18.43, ignoring the "Other" category). The upper portion of the table shows that each rollover group was overrepresented among the shallow curve accidents.

Table 8-37 shows the computations for the effect of impact behavior, in terms of rollovers versus nonrollover impacts, on injury for the two degree of curvature groups. The results show that impact behavior accounted for a 20 percent difference in the injury rate. This is 29 percent of the observed injury rate differential.

TABLE 8-36 IMPACT BEHAVIOR BY DEGREE OF CURVATURE FOR LEFT CURVES

	Degree of Curvature			
	0 - 8		9+	
Behavior	N	%	N	%
Rollover:				
< 360°	247	23.3	62	20.5
360°	132	12.4	25	8.3
> 360°	112	10.5	27	8.9
Compound	51	4.8	11	3.6
Total	542	51.0	125	41.4
Nonroll Impact:				
Stop	161	15.2	75	24.8
Thru or Over	43	4.0	14	4.6
Continue	310	29.2	88	29.1
Other	6	0.6	0	0.0
Total	520	49.0	177	58.6
Total	1,062	100.0	302	100.0

TABLE 8-37 IMPACT BEHAVIOR AS AN EXPLANATORY FACTOR FOR THE EFFECT OF DEGREE OF CURVATURE ON INJURY

		Degree of Curvature				
		0 - 8		9+		
Behavior	% Injured	% in Behavior Class	Product	% in Behavior Class	Product	Injury Rate Differential (%)
Rollover	72.4	51.0	36.9	41.4	30.0	
Nonroll Impact	51.9	49.0	25.4	58.6	30.4	
Estimated Rate (Sum)			62.4		60.4	2.0
Observed Rate			58.4		51.5	6.9

Rate Differential Associated with Impact Behavior: 2.0/6.9 = 29.0%

The next two tables, 8-38 and 8-39, show area of damage and object struck for left curves above and below eight degrees. Neither relationship was statistically significant (X_3^2 = 0.52 for area of damage; X_9^2 = 3.64 for object struck; both reflecting only rows with at least 20 observations). Neither table contained large enough differences to account for a meaningful effect upon injury.

TABLE 8-38 AREA OF DAMAGE BY DEGREE OF CURVATURE FOR LEFT CURVES

Area	Degree of Curvature			
	0 - 8		9+	
	N	%	N	%
Front	306	59.6	102	58.6
Left	89	17.3	35	20.1
Back	10	1.9	3	1.7
Right	49	9.6	17	9.8
Top	9	1.8	0	0.0
Undercarriage	50	9.7	17	9.8
Total	513	100.0	174	100.0

TABLE 8-39 OBJECT STRUCK BY DEGREE OF CURVATURE FOR LEFT CURVES

Object	Degree of Curvature			
	0 - 8		9+	
	N	%	N	%
Ditch	40	8.8	12	7.8
Embankment	62	13.7	18	11.8
Field Approach	15	3.3	2	1.3
Culvert	33	7.3	8	5.2
Ground	15	3.3	7	4.6
Small Sign Post	10	2.2	1	0.7
Wooden Utility Pole	52	11.5	22	14.4
Tree	80	17.7	31	20.3
Trees, Brush	42	9.2	16	10.5
Rock(s)	16	3.5	8	5.2
Fence	44	9.7	14	9.2
Guardrail	33	7.3	11	7.2
B/O - Side Rail	7	1.5	2	1.3
B/O - Entrance	4	0.9	1	0.7
Total	453	100.0	153	100.0

Thus, the major contributor to the lower injury rate on the sharper left curves was reduced impact speed. This was probably attributable to lower travel speeds for these curves. Secondly, even though vehicles were less often tracking when departing the sharper curves, they experienced fewer rollovers of all kinds.* This, too, contributed to the lower injury rate.

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*It is conceivable, while the vehicles were less likely to be tracking when departing the sharper curves, that their yaw angle (as opposed to departure angle) could be small. This would be consistent with the shorter tire marks in that less road space was available to develop a large yaw angle.

8.5 Guardrail Impacts

8.5.1 Impact Angle

An important concern regarding guardrails is the angle at which they are struck, since this should form the basis for standards testing procedures. While impact angle information was not obtained in this study, it was thought that departure angle might be a useful surrogate, particularly when the offset was small. However, in attempting the analysis, a difficulty was encountered in that the number of small offset guardrails struck was low. Therefore, Table 8-40 was developed in which departure angle distributions were found first for guardrail offsets of zero to three feet, then zero to six feet, etc. Thus, in the upper portions of the table, departure angle provides a good estimate of impact angle but reliability is limited by low frequencies. In the lower portions, the estimates of impact angle may not be as rigorous, but the number of observations is higher.

In studying the results, there was the good fortune that the median departure angle was quite stable, irrespective of the data set used. Specifically, the median departure angle and, by inference, the median guardrail impact angle was consistently in the nine to eleven degree range.

On the other hand, it should be noted that only fifteen to seventeen percent of the guardrail strikes fell in this range. Approximately 40 percent of the angles were smaller and 45 percent larger. Looking at the extremes, over twenty percent were below six degrees, and twenty-five to thirty percent were above twenty degrees. Thus, almost fifty percent were at angles either less than half or more than twice the median range.

It is important to recognize that these results must be interpreted with a view to the fact that while most guardrails are parallel to the road, not all are. This will introduce additional variability into the estimated impact angles. In particular, the portions of impacts at small angles and at large angles are likely to be even larger than those indicated above.

TABLE 8-40 DEPARTURE ANGLE FOR STRUCK GUARDRAILS (First Event)

	Departure Angle (Degrees)										
	0-2	3-5	6-8	9-11	12-14	15-20	21-29	30-45	46-79	80-90	Total
- Lateral Distance = 0-3' -											
N	2	5	5	5	2	1	1	4	2	2	29
% Dept. Angle	6.9	17.2	17.2	17.2	6.9	3.4	3.4	13.8	6.9	6.9	100.0
Cumulative %	6.9	24.1	41.4	58.6	65.5	69.0	72.4	86.2	93.1	100.0	
- Lateral Distance = 0-6' -											
N	4	16	16	13	5	9	5	8	5	5	86
% Dept. Angle	4.7	18.6	18.6	15.1	5.8	10.5	5.8	9.3	5.8	5.8	100.0
Cumulative %	4.7	23.3	41.9	57.0	62.8	73.3	79.1	88.4	94.2	100.0	
- Lateral Distance = 0-9' -											
N	7	22	25	19	8	18	8	10	6	7	130
% Dept. Angle	5.4	16.9	19.2	14.6	6.2	13.8	6.2	7.7	4.6	5.4	100.0
Cumulative %	5.4	22.3	41.5	56.2	62.3	76.2	82.3	90.0	94.6	100.0	
- Lateral Distance = 0-12' -											
N	10	29	32	27	11	29	21	12	7	7	185
% Dept. Angle	5.4	15.7	17.3	14.6	5.9	15.7	11.4	6.5	3.8	3.8	100.0
Cumulative %	5.4	21.1	38.4	53.0	58.9	74.6	85.9	92.4	96.2	100.0	

8.5.2 Vehicle Impact Behavior for Guardrail Strikes

Next, guardrail impacts were examined for ensuing vehicle behaviors. The results are in Table 8-41. They indicate less than optimal guardrail performance.

TABLE 8-41 VEHICLE BEHAVIOR FOR GUARDRAIL STRIKES

(All Events)

Behavior	N	%
No Rollover:		
Vault	13	2.5
Stop	64	12.3
Thru, or Over	163	31.4
Redirect to Road	128	24.7
Continue	135	26.0
Other	2	0.4
Rollover and:		
Stop	2	0.4
Continue	5	1.0
Other	7	1.3
Total	519	100.0

First, almost one-third of the vehicles went through or over the guardrails they struck. Another three percent vaulted (became airborne) as a result of hitting guardrails. Twelve percent of the vehicles came to an essentially immediate stop after hitting guardrails. Unless the impact speeds were low, this, too, is undesirable. In this regard, of 64 vehicles stopping on impact, 57 had estimated impact speeds. For them, the mean speed was 13 MPH, with a standard deviation of 7 MPH. (For the total of 477 estimated guardrail impact speeds for all types of vehicle behaviors, the mean was 33 MPH and the standard deviation was 17 MPH.)

The most desirable consequence of hitting a guardrail is continued travel without going through or over it and without returning to the road; this occurred for 26 percent of these guardrail strikes. A somewhat less desirable consequence is returning to the road. The assumption here is that the likelihood of being struck by another vehicle is sufficiently low that returning to the road is preferable to striking the hazard shielded by the guardrail. Twenty-five percent of the guardrail strikes resulted in redirection back into the road.

Using test evaluation criteria in NCHRP Report 153 (Reference 90), 176 (34%) of the impacts clearly violated specified guardrail performance in that vaulting or guardrail penetration occurred. Another 64 (12%) may or may not have violated performance specifications; these were the vehicles which stopped immediately after impact. Since actual momentum changes were, of course, not known, these impacts could not be evaluated here.

8.5.3 Injury in Guardrail Impacts

Considering driver injury* as a function of vehicle behavior in all guardrail impacts, it can be seen in Table 8-42 that the two most dangerous vehicle behaviors were vaulting and traveling through or over the guardrail; note, however, that there were only thirteen occurrences of vaulting, thus making inferences risky. Moderately surprising was the relatively low severity associated with vehicles which stopped upon impact. This, however, was not totally unexpected, in light of the previous results showing that impact speeds connected with stopping behavior were lower than those of other vehicle behaviors.

TABLE 8-42 DRIVER INJURY BY VEHICLE BEHAVIOR FOLLOWING GUARDRAIL IMPACTS

	Injury				Injured		
Behavior	None	Nonfatal	Fatal	Total	N	%	% Killed
Vault	2	8	3	13	11	84.6	23.1
Stop	43	20	1	64	21	32.8	1.6
Through or Over	80	76	4	160	80	50.0	2.5
Redirect to Road	84	42	1	127	43	33.9	0.8
Continue	83	51	1	135	52	38.5	0.7
Stop During Rollover	1	1	0	2	1	50.0	0.0
Continue During Rollover	0	5	0	5	5	100.0	0.0
Unknown, Other	1	8	0	9	8	88.9	0.0
TOTAL	294	211	10	515	221	42.9	1.9

* Driver, rather than occupant, injury was used to provide greater precision by removing the effects of the number of occupants.

Other behaviors with relatively low injury rates were redirection to the road and continue. Regarding vehicles which struck a guardrail and were deflected back into the road, one might assume this could be less than ideal since it might result in a collision with another vehicle. However, if such a secondary impact had occurred, the accident would have been excluded from the study sample since it contained only single vehicle accidents. Therefore, the tabulated results tend to underestimate the injury rate associated with redirection to the road.

Guardrail impacts followed by continued travel, but not returning to the road and not passing through or over the guardrail, are considered to reflect ideal guardrail functioning. By comparison to the overall driver injury rate of 52 percent (Table 6-1), the 39 percent injured for guardrail impact-and-continue tends to confirm this view. However, the 33 percent rate for guardrail impact-and-stop was even better. One would prefer to have more observations before drawing conclusions from this latter contrast.

The accidents which were tabulated in Table 8-42 were further examined in order to determine if there were any in which an impact had occurred between a vehicle's departure and initial guardrail contact. This could conceivably confound the results, but no such instances were found.

Table 8-43 presents the driver injury distributions for the various event types in primary guardrail impacts. Note that for every vehicle behavior, injury rate was less than or comparable to the corresponding value in Table 8-42. Thus, a relatively desirable outcome of an accident situation may very well be a primary impact with a guardrail.

TABLE 8-43 DRIVER INJURY BY VEHICLE BEHAVIOR FOLLOWING PRIMARY GUARDRAIL IMPACTS

Behavior	Injury			Total	Injured		% Killed
	None	Nonfatal	Fatal		N	%	
Vault	1	0	0	1	0	0.0	0.0
Stop	31	16	1	48	17	35.4	2.1
Through or Over	53	17	3	73	20	27.4	4.1
Redirect to Road	53	18	0	71	18	25.4	0.0
Continue	63	25	1	89	26	29.2	1.1
Stop During Rollover	1	1	0	2	1	50.0	0.0
Continue During Rollover	0	3	0	3	3	100.0	0.0
Unknown, Other	1	4	0	5	4	80.0	0.0
TOTAL	203	84	5	292	89	30.5	1.7

Table 8-43 also shows that there were five fatalities sustained as a result of a primary impact with a guardrail. Four of these occurred in single impact accidents; the remaining fatality involved other contacts after the vehicle went through a guardrail. As can be seen from the table, four of the fatal accidents occurred when there were undesirable post-guardrail behaviors, i.e., stop and through and over. The fatal case in which the vehicle behavior was "continue" involved driver ejection. All five of these fatal accidents were collisions with W-beam type guardrails.

Table 8-44 gives driver injury for the different types of guardrails; only blocked W-beam guardrails had sufficiently large frequencies of contact to allow further sub-division.

TABLE 8-44 DRIVER INJURY BY TYPE OF PRIMARY GUARDRAIL IMPACTS

Guardrail Type	Injury: None	Injury: Nonfatal	Injury: Fatal	Total	Injured: N	Injured: %	% Killed
Blocked W-Beam (wood post)	51	19	1	71	20	28.2	1.4
Blocked W-Beam (light steel post)	5	2	0	7	2	28.6	0.0
Blocked W-Beam (steel post)	34	28	2	64	30	46.9	3.1
Non-Blocked W-Beam	22	6	2	30	8	26.7	6.7
Box Beam	11	3	0	14	3	21.4	0.0
3 Strand Cable	14	3	0	17	3	17.6	0.0
2 Strand Cable	12	1	0	13	1	7.7	0.0
Wood Post	3	1	0	4	1	25.0	0.0
Parapet	8	3	0	11	3	27.3	0.0

It appears from this table that steel post W-beam guardrails were the least effective in terms of mitigating injury ($X_1^2 = 5.28$, when contrasted to other blocked W-beams). The reason for this increased hazard would be best determined by a detailed clinical analysis of the mechanisms behind driver injury in the various guardrail collisions. Future efforts might incorporate such an approach.

The effectiveness of guardrails in protecting accident-involved vehicles from severe contacts with other roadside objects was also evaluated. Driver injuries from contacts with other objects after impacts with guardrails were compared with the corresponding injury distributions for impacts without any intervening guardrail contacts. This analysis was restricted to one and two impact accidents, since additional impacts would confuse the source of injury. Unfortunately, as can be seen in Table 8-45, the analysis was hampered by a scarcity of data points.

TABLE 8-45 DRIVER INJURY SEVERITY BY SECOND OBJECT STRUCK AFTER GUARDRAIL CONTACT

Second Object Struck	After Guard Rail Contact								Single Impact Accidents			
	No Injury		Injury		Fatal		Total		% No Injury	% Injury	% Fatal	Total Frequency
	N	%	N	%	N	%	N	%				
Ground	19	27.9	48	70.6	1	1.5	68	100.0	41.2	54.4	4.4	3,421
Tree	2	40.0	2	40.0	1	20.0	5	100.0	35.5	59.9	4.5	397
Ditch	2	40.0	3	60.0	0	0.0	5	100.0	61.7	37.5	0.9	112
Embankment	5	62.5	3	37.5	0	0.0	8	100.0	47.7	49.7	2.6	302
Fence	3	42.9	4	57.1	0	0.0	7	100.0	81.7	17.8	0.4	241
Guard Rail	36	85.7	6	14.3	0	0.0	42	100.0	70.8	27.1	2.1	192
Other	14	70.0	6	30.0	0	0.0	20	100.0	--	--	--	--
TOTAL	81	52.3	72	46.5	2	1.3	155	100.0				

For those objects which had sufficiently large frequencies, i.e., ground and additional guardrail contacts, the results were contradictory. At first glance, it appears as if guardrails had a mitigating effect on other guardrail contacts; however, this result was probably more indicative of situations in which the vehicle was deflected slightly from the guardrail prior to a second contact with it. This is, in fact, optimal guardrail performance, i.e., decelerating the vehicle over a relatively long period of time; the decreased driver injury severity in these cases is encouraging.

However, in post-guardrail ground contacts, it appears that the driver was exposed to increased risk; the injury rate (nonfatal plus fatal injury) was 13 percent higher than that for accidents in which only the ground was contacted. On this basis, it might be argued that the imposition of a guardrail between the road and terrain conducive to rollovers is counter-productive. However, there is another factor precluding this conclusion. In the accidents cited, the guardrails may well have been introduced specifically to protect vehicles from hazardous terrain. In that case, one would expect greater risk for vehicles exposed to that terrain than to land where no guardrail was necessary. Thus, without further study, the reasons for the injury rate differential could not be specified.

8.5.4 Other Objects as Protective Barriers

Fences

Fences might also serve to protect occupants from more severe contacts. Table 8-46 presents the injury distributions associated with objects struck after a fence impact for applicable two impact accidents. As in Table 8-45, the single impact injury distributions for each object is also presented.

The two objects with a meaningful number of impacts (ground and trees) had quite similar injury experience for the two conditions. The largest differences occurred for ditches and fences, but they were in opposite directions and the frequencies were low. Thus, these data suggest little to recommend fences as useful barriers.

TABLE 8-46 DRIVER INJURY SEVERITY BY SECOND OBJECT STRUCK AFTER FENCE CONTACT

Second Object Struck	After Fence Contact								Single Impact Accidents			
	No Injury		Injury		Fatal		Total		% No Injury	% Injury	% Fatal	Total Frequency
	N	%	N	%	N	%	N	%				
Ground	50	42.7	58	49.6	9	7.7	117	100.0	41.2	54.4	4.4	3,421
Tree	14	34.1	24	58.5	3	7.3	41	100.0	35.5	59.9	4.5	397
Wooden Utility Pole	14	50.0	14	50.0	0	0.0	28	100.0	55.6	43.9	0.5	383
Ditch	10	71.4	4	28.6	0	0.0	14	100.0	61.7	37.5	0.9	290
Embankment	4	50.0	4	50.0	0	0.0	8	100.0	47.7	49.7	2.6	302
Fence	9	69.2	4	30.8	0	0.0	13	100.0	81.7	17.8	0.4	241
Trees, Brush	6	66.7	3	33.3	0	0.0	9	100.0	66.3	32.2	1.5	202
Other	11	57.9	7	36.8	1	5.3	19	100.0	--	--	--	--
TOTAL	118	47.4	118	47.4	13	5.2	249	100.0				

Trees, Brush

A third object type - small trees and brush - which has the potential to protect vehicle occupants from additional impacts was also evaluated; the results are given in Table 8-47. Obviously, this analysis was hindered by small sample sizes. The proportions of accidents resulting in an injury or fatality if trees and brush were contacted first were 21 percent and 20 percent lower for ground and tree impacts, respectively. However, for secondary impacts with trees and brush, the rate was 16 percent higher. Further study of this topic might well prove fruitful.

In order to compare the effectiveness in preventing additional impacts of the three previously discussed protective devices, Table 8-48 was prepared; since all accidents were used, this analysis was not restricted by the small cell frequencies as were the analyses utilizing the driver injury distributions.

As can be seen, trees and brush had the smallest proportion of secondary impacts; guardrails and fences performed about equally, with less than half of the accidents being confined to single impacts. However, in the tables of driver injury severity for second object struck, it was documented that a portion of the second contacts were additional impacts with the same protective barrier. If these are assumed to be analogous to single impact accidents, then the proportion of accidents with only one impact would be 58.4%, 46.9%, and 82.8% for guardrails, fences, and trees and brush, respectively. Unfortunately, no definitive statement can be made from these data, as the first impact speed varied, depending on the type of object struck, the mean first impact speed for guardrails was 32.11 MPH, fences struck were at an average speed of 37.29 MPH, and trees and bushes at 23.55 MPH. The number of applicable accidents was too small to control for impact speed in the analyses.

TABLE 8-47 DRIVER INJURY SEVERITY BY SECOND OBJECT STRUCK AFTER CONTACTING TREES AND BRUSH (TWO IMPACT ACCIDENTS)

	After Tree or Brush Contact								Single Impact Accidents			
Second Object Struck	No Injury		Injury		Fatal		Total		% No Injury	% Injury	% Fatal	Total Frequency
	N	%	N	%	N	%	N	%				
Ground	13	61.9	8	38.1	0	0.0	21	100.0	41.2	54.4	4.4	3,421
Tree	5	55.5	4	44.4	0	0.0	9	100.0	35.5	59.9	4.5	397
Trees, Brush	4	50.0	2	25.0	2	25.0	8	100.0	66.3	32.2	1.5	202
Other	5	71.4	2	28.6	0	0.0	7	100.0	--	--	--	--
TOTAL	27	60.0	16	35.6	2	4.4	45	100.0				

TABLE 8-48 NUMBER OF IMPACTS BY FIRST OBJECT STRUCK

Number Of Impacts	Guard Rail Struck First		Fence Struck First		Trees, Brush Struck First	
	N	%	N	%	N	%
1	195	48.0	248	44.5	214	79.9
2	157	38.7	253	45.4	47	17.5
3	47	11.6	45	8.1	7	2.6
4	6	1.5	11	2.0	0	0.0
5	1	0.2	0	0.0	0	0.0
TOTAL	406	100.0	557	100.0	268	100.0

8.5.5 Summary of Guardrail Impacts

1. The median impact angle for guardrail impacts was inferred to be between 9 and 11 degrees. However, it appeared that almost 50 percent of these impacts were at angles less than half or more than twice the median value, and that at least fifteen percent occurred at angles of 30 degrees or more.

2. Guardrail performance was less than optimal in that almost one-third of the striking vehicles went through or over the guardrails, 12 percent of the vehicles came to an immediate stop, and three percent vaulted the guardrails.

3. Mitigating the item above to some extent, the vehicles which stopped had a lower driver injury rate than did the composite of vehicles striking guardrails. On the other hand, those vaulting or otherwise traveling through or over the guardrails had a driver injury rate in excess of the composite value. Finally, the composite driver injury rate for guardrail strikes was less than that for all accidents.

4. When the primary impact involved a guardrail, the driver injury rate was 30 percent. This was lower than the value for all guardrail impacts, further suggesting guardrail benefits.

5. Steel post blocked W-beam guardrails had a 47 percent driver injury rate, compared to 28 percent for wood post blocked W-beams and only thirteen percent for cable guardrails.

6. There was some evidence that small trees and brush could act to reduce accident severity. Earlier results (cf. Table 6-8) had shown the injury rates for primary impacts with trees and brush was low. Secondly, findings in the current section showed that the number of impacts in an accident was likely to be lower if the first impact involved small trees or brush than if it involved guardrails or fences; however, this may have been due to differential impact speeds.

8.6 Extent of Vehicle Damage

The Collision Deformation Classification (CDC), previously referenced in Section 6, was used to describe vehicle damage. Some aspects of the CDC were used in other parts of the report; they were direction of force and general area of damage. Another aspect of the CDC is the extent of damage; its relationship to injury is discussed in the following.

One important feature of the damage extent portion of the CDC should be noted. It does not reflect simply a measure of the amount of damage incurred. Rather, it attempts to describe the apparent threat to the integrity of the passenger compartment. This is done by partitioning the vehicle into zones which represent various levels of severity. At the front and rear of the vehicle, there are five equally spaced zones outside the passenger compartment. At the top of the vehicle, there are two zones outside the passenger compartment with the first zone representing only surface damage. Thus, vehicle crush of 2 inches, for example, at the top of the vehicle, would receive an extent classification of 2 whereas the same amount of crush at the front would be classified only a 1. To receive a classification of 2 at the front of the vehicle, as many as 12 or more inches of crush would be required, depending on the vehicle. In the case of certain types of vans and cab-over truck tractors, the length of each frontal zone may be quite small, by comparison, since the same rules of zone division apply. The extent classification is also different at the side of the vehicle. Here, the first zone extends as far as the bottom of the side glass; the second zone extends to the top of the glass. One other factor should be noted. Not only do comparable amounts of crush receive different extent classifications depending on the location of the damage, but, since the resistance to crush also differs at different locations on the vehicle, the force applied for a given extent code also may have differed considerably depending on the location of the impact.

Extent of damage ranges in value from 0 (no damage) to 9 (extremely severe damage). For the purposes of this report, however, damage extents of five or greater were grouped together, due to the low frequencies with which they occurred. Unlike the injury, one has (theoretically) an estimate of the severity for each impact. Table 8-49 presents the frequency distributions of damage extent for three classes of impact.

TABLE 8-49 DISTRIBUTIONS OF EXTENT OF VEHICLE DAMAGE

Extent	All Impacts		Primary Impacts		Single Impact Accidents	
	Freq.	%	Freq.	%	Freq.	%
0	10	0.1	10	0.1	4	0.1
1	131	1.2	15	0.2	8	0.2
2	5,013	45.7	2,263	30.4	1,601	34.8
3	2,185	19.9	1,767	23.8	1,145	24.9
4	2,560	23.3	2,367	31.8	1,347	29.3
5	665	6.1	638	8.6	327	7.1
6	211	1.9	202	2.7	88	1.9
7	151	1.4	139	1.9	61	1.3
8	26	0.2	24	0.3	13	0.3
9	12	0.1	12	0.2	3	0.1
Unknown	806	---	500	---	322	---
TOTAL	11,770	100.0	7,937	100.0	4,919	100.0

Not surprisingly, the overall extent from all impacts was less severe than the single impacts, which in turn were less severe than the primary impacts. This was based on the median extents of damage for the three impact types, which were calculated to be 3.15, 3.60, and 3.81 for all impacts, single impacts and primary impacts, respectively.

The extent of vehicle damage is a better estimate of the physical characteristics of the impact than of occupant injury. However, the primary purpose of highway safety research is to reduce the number of injuries and fatalities resulting from highway accidents; reduction of vehicle damage is largely relevant only to the extent that it relates to occupant injury. Figure 8-1 shows the percent of drivers injured versus extent of vehicle damage in primary impacts; not surprisingly, there was a strong monotonic relationship.

As discussed earlier, the force and deformation required to produce a specified extent of damage vary as a function of area of impact. The effect of impact area on the relationship between damage extent and driver injury is shown in Table 8-50.

These results reflect the importance of both area and extent of damage on driver injury. However, the interaction between extent and area of damage was not excessive. In almost all instances, the monotonic relationship between injury and extent was maintained. This was also true for the proportion killed with the exception of top damage. (This usually reflects rollovers, where ejections are important in influencing injury.) Furthermore, the ranking of area of damage in terms of injury is relatively constant from one extent class to another. For example, the likelihood of injury was lowest for rear impacts, followed by side impacts, and then front and top (mostly rollover) impacts. Where there were sufficient observations, undercarriage impacts were second next to rear impacts.

FIGURE 8-1 INJURY RATE BY EXTENT OF DAMAGE FOR PRIMARY IMPACTS

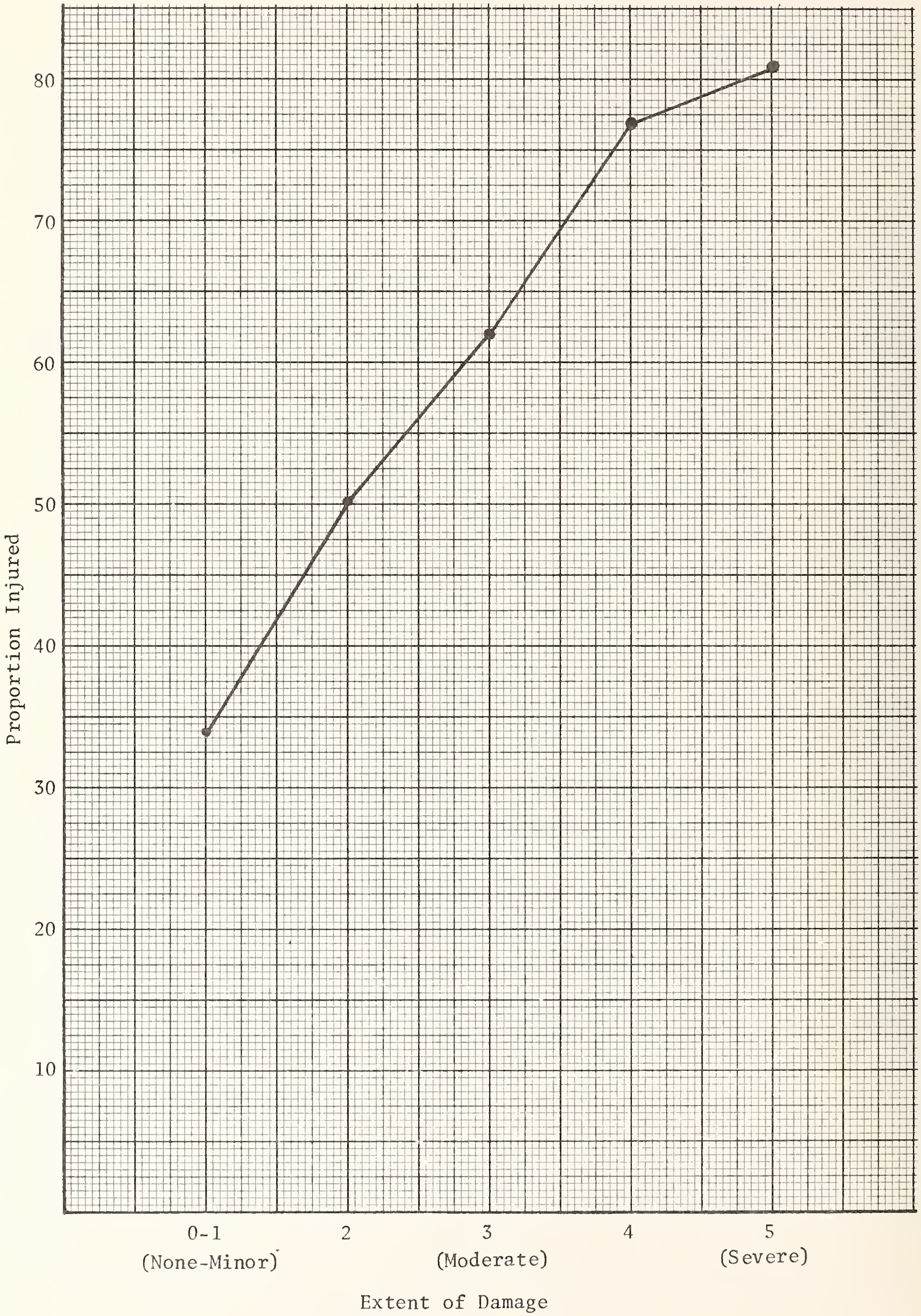

TABLE 8-50 DRIVER INJURY SEVERITY VERSUS EXTENT OF VEHICLE DAMAGE WITHIN GENERAL AREAS OF DAMAGE (SINGLE IMPACTS)

Driver Injury Severity	Extent 1 N	1 %	2 N	2 %	3 N	3 %	4 N	4 %	≥ 5 N	≥ 5 %
- Frontal Impacts -										
Not Injured	2	100.0	556	64.1	225	43.6	36	22.0	21	24.7
Injured	0	0.0	308	35.5	278	53.9	115	70.1	50	58.8
Fatal	0	0.0	4	0.5	13	2.5	13	7.9	14	16.5
TOTAL	2	100.0	868	100.0	516	100.0	164	100.0	85	100.0
- Right Side Impacts -										
Not Injured	1	100.0	191	82.0	150	63.3	57	44.5	7	25.9
Injured	0	0.0	42	18.0	86	36.3	69	53.9	19	70.4
Fatal	0	0.0	0	0.0	1	0.4	2	1.6	1	3.7
TOTAL	1	100.0	233	100.0	237	100.0	128	100.0	27	100.0
- Rear Impacts -										
Not Injured	0	-	44	88.0	13	76.5	6	50.0	5	83.3
Injured	0	-	6	12.0	4	23.5	6	50.0	0	0.0
Fatal	0	-	0	0.0	0	0.0	0	0.0	1	16.7
TOTAL	0	-	50	100.0	17	100.0	12	100.0	6	100.0
- Left Side Impacts -										
Not Injured	1	100.0	143	76.5	112	63.3	37	48.1	1	4.8
Injured	0	0.0	43	23.0	62	35.0	38	49.4	18	85.7
Fatal	0	0.0	1	0.5	3	1.7	2	2.6	2	9.5
TOTAL	1	100.0	187	100.0	177	100.0	77	100.0	21	100.0
- Top Impacts -										
Not Injured	0	-	9	42.9	54	56.3	397	42.5	85	25.0
Injured	0	-	10	47.6	41	42.7	503	53.9	220	64.7
Fatal	0	-	2	9.5	1	1.0	34	3.6	35	10.3
TOTAL	0	-	21	100.0	96	100.0	934	100.0	340	100.0
- Undercarriage Impacts -										
Not Injured	1	100.0	145	69.7	49	64.5	4	50.0	0	0.0
Injured	0	0.0	62	29.8	26	34.2	4	50.0	2	66.7
Fatal	0	0.0	1	0.5	1	1.3	0	0.0	1	33.3
TOTAL	1	100.0	208	100.0	76	100.0	8	100.0	3	100.0

Table 8-51 presents the extent of damage classification for the various areas of damage in nonrollover impacts. In terms of the proportion of damage extents greater than or equal to three, top impacts had the most, followed by left and right side impacts, rear impacts, frontal impacts, and undercarriage contacts, which were last. Note that damage to the top in nonrollover accidents was the result of events such as a sheared utility pole falling on the vehicle.

The problem here is that it is virtually impossible to determine from these data whether the differences primarily reflect differential impact severity or the differences in the definition of extent zone from area to area. That the proportion of extents greater than or equal to three were the same for left and right side impacts where the definitions are equivalent shows the impact severity for left and right side impacts were quite similar. But no such conclusions can be reached for other area of impact comparisons.

As an example, these results show frontal impacts ranked very low with regard to extent of damage. In contrast to this, earlier results (Section 6) had shown that, aside from top impacts, frontals had the highest injury rate among the nonrollover impacts. This is, in fact, consistent with the definition and intent of the extent code. It reflects the fact that passenger compartment intrusions are relatively infrequent in frontal impacts; rather, occupant movement usually determines the nature of his contacts with the vehicle interior and, hence, the resultant injury.

In general, then, several conclusions can be drawn regarding the relationship between extent of damage and injury. In single vehicle accidents, extent of damage was an important correlate of injury. The driver injury rate extended from 33 percent to 79 percent as a function of damage extent. On the other hand, the failure to take area of damage into account can lead to severe distortions in predicted injury. This was evident in that the extent of damage was low and the injury rate high for frontal impacts in comparison to other impact areas. (This reflects the emphasis of the extent code on compartment integrity, rather than on ΔV).

TABLE 8-51 EXTENT OF DAMAGE BY AREA OF DAMAGE FOR ALL NONROLLOVER IMPACTS

	Area of Damage											
	Front		Right		Back		Left		Top		Under-carriage	
Extent Classification	N	%	N	%	N	%	N	%	N	%	N	%
0	12	0.3	1	0.1	1	0.6	0	0.0	0	0.0	6	0.9
1	2,986	68.3	531	53.3	104	61.5	390	50.8	4	9.5	509	72.8
2	937	21.4	264	26.5	37	21.9	220	28.6	4	9.5	147	21.0
3	290	6.6	151	15.2	20	11.8	118	15.4	12	28.6	28	4.0
4	65	1.5	32	3.2	3	1.8	32	4.2	7	16.7	6	0.9
5 or more	83	1.9	17	1.7	4	2.4	8	1.0	15	35.7	3	0.4
Total	4,373	100.0	996	100.0	169	100.0	768	100.0	42	100.0	699	100.0
% Greater or Equal to 3	10.0		20.1		16.0		20.6		81.0		5.3	

Within a given impact area these distortions did not arise, with the possible exception of top impacts where ejections play an important role. That extent of damage was a good predictor of injury, even when impact area was ignored, may well reflect the preponderance of frontal impacts in single vehicle accidents.

8.7 Impacts with Culverts

There were 444 impacts with culverts in the sample. Of these culverts, 171 (39%) ran under the road from which the vehicle had departed, 252 (57%) ran under another road, and for 21 (5%), the culvert either ran under something other than a road or it was unknown which road it ran under. The question under study here was whether there is evidence that vehicles became "trapped" by ditches and were thereby directed toward the culverts.

One of the variables providing information for such an analysis was "contour". This variable gives a description of the contour of the terrain at the point of impact. It reflects a cross section of the terrain cut at right angles to the departure road and is oriented in a direction away from the road. For example, ( ) was coded when the impact occurred near the top of a downslope; the same code was used for either the left hand or right hand side of the road. Note that the contour does not reflect, and is independent of, the direction of travel of the vehicle.

Table 8-52 contains the distribution of contours for all culvert impacts. It shows that of all such impacts, 262 (59%) occurred within ditches running parallel to the departure road. Eighty-two (18%) occurred on downslopes, 24 (5%) occurred near the top of downslopes, and 13 (3%) occurred near the bottom of downslopes; of these, the first two are somewhat ambiguous in that the downslopes may have been associated with road fill or the near side of ditches. Thus, the likely proportion of culvert impacts in ditches parallel to the road ranged from 59 percent to 83 percent.

TABLE 8-52 GROUND CONTOUR FOR CULVERT IMPACTS

Contour		Frequency	Percent
Ditch	(V)	262	59.0
Downslope	(\)	82	18.5
Top of Downslope	(—\)	24	5.4
Bottom of Downslope	(_)	13	2.9
Flat	(_)	25	5.6
Other		38	8.6
TOTAL		444	100.0

These results, however, merely imply that most impacted culverts were in ditches running parallel to the departure road. (The 25 impacts with culverts on a flat contour probably reflect ditches or fill running at right angles to the departure road.) To this point then, the results do not show whether vehicles were traveling within ditches prior to impacting the culverts.

While there was no information specifically detailing the terrain contour along the vehicle's path, the general direction in which the vehicle was traveling immediately prior to impact was coded. By restricting impacts to culverts which ran under a road other than the departure road and were therefore presumably parallel to the departure road, one can examine the proportion of vehicles whose direction was parallel to the road and therefore probably in the ditch. Table 8-53 gives vehicle direction cross-tabulated with contour for such culvert impacts.

These data show that most vehicles (77%) were traveling away from the departure road when striking a culvert. Only 51 (20%) were traveling parallel to the road. Even for those impacts specifically occurring in ditches which ran parallel to the road, only nineteen percent of the vehicles were in a path parallel to the road. Thus, although the ditches ran parallel to the road, in most instances, the vehicle's path did not. As such, the data provided no basis for the view that vehicles directed toward culverts by ditches was a serious problem.

TABLE 8-53 VEHICLE DIRECTION AND GROUND CONTOUR FOR CULVERT IMPACTS

(Culverts Under Other Road)

Vehicle Direction Relative to Departure Road	(V)		(\)		(‾\)		(_)		(—)		Else		Total	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Away	172	78.2	10	100.0	1	33.3	0	-	6	60.0	6	66.7	195	77.4
Parallel	42	19.1	0	0.0	2	67.7	0	-	4	40.0	3	33.3	51	20.2
Toward	6	2.7	0	0.0	0	0.0	0	-	0	0.0	0	0.0	6	2.4
TOTAL	220	100.0	10	100.0	3	100.0	0	-	10	100.0	9	100.0	252	100.0

One question does remain, however. The results above suggest that the magnitude of the problem is not large: less than 20 percent of culvert impacts could be identified as involving vehicles which could have been traveling in ditches leading to culverts. However, these data do not address the question of whether such ditches are conducive to culvert impacts. For this purpose, Table 8-54 was developed.

TABLE 8-54 CULVERT IMPACTS BY VEHICLE DIRECTION FOR IMPACTS IN DITCHES

(Culverts Under Other Roads)

Vehicle Direction Relative to Departure Road	Culvert Impacts		Other Events in Ditches	
	N	%	N	%
Parallel	42	19.1	226	13.9
Not Parallel	178	80.9	1,405	86.1
TOTAL	220	100.0	1,631	100.0

The results pertain only to events occurring in ditches parallel to the departure road. They show that the likelihood of traveling parallel to the road, and presumably in the ditch, was higher for vehicles striking culverts than for vehicles experiencing other events. On the other hand, the magnitude of the difference was not large. Because of this, a chi-square test was run and found to be significant at the .05 level ($X_1^2 = 4.29$).

Thus, it seems likely that some culverts were struck because vehicles were directed toward them by ditches; however, this appears to be applicable to less than twenty percent of the culvert impacts.

8.8 ADT Effects on Accident Rates

An attempt was made to provide information regarding the advisabiilty of applying stringent road standards to low volume roads. To do so, road mileage data were collected for rural, county roads in Georgia since it was found that the required data for this state were in the most accessible form.

In preparing the data, section length was multiplied by ADT for each road section, and the products were summed over sections within ADT groupings to provide estimates of daily vehicle mileage. Since ADT's were not consistently specified for roads with fewer than 400 vehicles per day, vehicle mileage for this ADT range was obtained by subtracting the sum of the state-provided road mileage for higher volume roads from the total mileage for rural, county roads obtained from the 1974 Highway Statistics (Reference 92). The result was multiplied by 200 to give estimated vehicle miles traveled on roads with an ADT of less than 400. The accident rates were calculated as the number of accidents divided by the daily vehicle mileage, with the ratio divided by the number of days (304) in the accident data collection period.

In Table 8-55, the total number of accidents (reported in this study), computed vehicle mileage (per day), and a resultant accident rate are shown for each ADT grouping.

TABLE 8-55 SINGLE VEHICLE ACCIDENT RATE AS A FUNCTION OF ADT

ADT	Number of Accidents	Daily Vehicle Miles (X 100,000)	Accident Rate (per Billion Vehicle Miles)
1- 399	293	131.19*	73.5
400- 999	50	16.86 (1207)**	97.6
1000-1999	30	11.08 (433)	89.1
2000-4999	19	10.77 (292)	58.0
≥5000	6	11.07 (80)	17.8

*Estimated by subtraction

**Number of road sections for vehicle mileage base

The results show an increase in the single vehicle accident rate from the first ADT range (1-399) to the second (400-999). Above that, the rate decreased monotonically with ADT.

Of course, these data must be interpreted cautiously due to the very limited number of accidents in the sample for the higher ADT roads. On the other hand, the systematic rate reduction above 400 ADT lends credibility to the results for the higher volume roads. A question remains, however, as to whether the low value below 400 ADT is reliable. Because the accident data and the exposure data were obtained independently, no satisfying statistical answer could be provided. This is because the data could provide only results grouped by ADT, rather than by individual road sections; thus, the number of data points is low and any testing would be insensitive. On further consideration, the rate for the roads under 400 ADT was at least suspect for two reasons. First the likelihood of accidents being unreported is higher on more secluded roads. This would tend to yield an underestimated rate. Second, the calculation of vehicle mileage for these roads assumed an average ADT of 200 vehicles per day; this could be neither verified nor refuted, but must be considered a source of error.

For these reasons, an alternative approach was attempted. It was based on a simplistic cost/benefit model, which focused on the question of which roads, in terms of ADT category, deserve action to reduce single vehicle accidents. The assumptions are:

(1) The cost of remedial action depends solely on road length and not ADT. Thus, the model would be applicable to most roadside treatments. It would apply, for example, to road surface treatments only to the extent that the cost is heavily weighted by installation costs and maintenance costs that are independent of traffic volume.

(2) The benefits are measured in terms of the reduction in accident frequency, and the percent reduction is constant for all ADT. That is, the effect of a remedial treatment would be an x percent reduction in single vehicle accidents irrespective of ADT. This assumption seems reasonable, particularly as applied to single vehicle accidents on relatively low volume roads where the proportion of accidents involving vehicle interactions is low.*

The first assumption can be written as

$$\text{cost} = \alpha \times \text{ miles of road}$$

where α is a constant reflecting the cost per mile.

The second assumption is

$$\text{benefits} = \beta \times \text{ number of accidents,}$$

where β is a constant reflecting the magnitude of the improvement. β lies between zero and one. A value of zero reflects no accident reduction, and a value of one reflects prevention of all accidents. Note that a value of 0.10 implies either a ten percent reduction in the accident rate or in accident frequency.

With these two relationships, the potential benefits per unit cost (ρ) can be written

$$\rho = \frac{\beta \times \text{ number of accidents}}{\alpha \times \text{ miles of road}} \quad \text{, or}$$

$$\rho = K \times \frac{\text{number of accidents}}{\text{miles of road}}$$

* Of course, in this type of analysis, the payoff is measured in accident prevention, not injury reduction. This is not to deny the importance of the latter, but simply to reflect the focus of the analysis.

Since K, or β/α, is wholly a function of type of treatment, it is constant for all ADT. Thus, the potential benefits per unit cost is directly proportional to accidents per mile of road. The relevant data and results are given in Table 8-56.

TABLE 8-56 BENEFIT/COST POTENTIAL AS A FUNCTION OF ADT

ADT	Number of Accidents	Miles of Road	Accidents per 10^3 Miles
0- 399	293	65,596	4.5
400- 999	50	2,741	18.2
1000-1999	30	774	38.8
2000-4999	19	368	51.6
5000+	6	114	52.6

The results show, within the framework of the model, that the benefits achievable for a given cost increase with ADT. Not only is ρ at a minimum for ADT below 400, it is very much smaller than that for other ADT ranges.

Finally, to more fully understand the implications of the model itself so that its acceptability can be judged, the following is noted. If accident rates were constant over ADT, then ρ would be directly proportional to ADT. This is true because the number of accidents would be proportional to ADT times road mileage and, since cost remains proportional to mileage, the ratio, ρ, would be proportional to ADT alone. Thus, if one assumed a constant accident rate, the model would yield an increasing payoff per cost with increasing ADT. This is simply an implication of the model, and it is thought to be quite reasonable. If, on the other hand, the reader finds it unacceptable, he should also reject the model and the results of the analysis.

Thus, the findings in Table 8-56 imply that within the framework of the model, the potential benefits per cost are very low for low volume roads relative to the other roads. Notice that while underreporting of accidents on low volume roads may contribute to this result, the earlier problem of using 200 vehicles per day to represent roads under 400 ADT is not applicable. Regarding the underreporting, it is very unlikely that it could account for the magnitude of the difference in accidents per mile shown in the table.

8.9 Countermeasures

The following discussion includes a presentation of countermeasure types, cost of implementation, and a summary of countermeasure experiences of the states. Finally countermeasure needs are discussed for road alignment problems and for roadside objects.

For the following discussion, a countermeasure is defined as being a constructed improvement to an existing roadway which can be implemented while retaining the existing roadway and whose primary purpose is to improve the safety of the roadway. Countermeasures would generally be applicable to the rural non-freeway type roadway emphasized in this study. Acceptable countermeasures would have in common: a low initial cost, minimal right-of-way acquisition requirements, and minimal maintenance requirements.

8.9.1 Classification and Identification

Countermeasures were grouped into two classes including those which would be expected to reduce the accident potential of a hazardous location and those countermeasures which would be expected to reduce the severity of the accidents at the hazardous location without necessarily reducing the accident frequency. For some countermeasures, classification becomes somewhat nebulous. As an example, relocation of a roadside obstacle may reduce the chance of an impact if more recovery and maneuver room is made available for an off-road driver to avoid the obstacle and possibly avoid a reportable accident. Thus, the countermeasure can partially be classed as accident potential reducing. The additional roadside recovery area may also allow the driver to slow the vehicle sufficiently to render an impact with the relocated obstacle less severe. In this instance, the countermeasure would be classed as accident severity reducing. For ease in discussion, any countermeasure designed to decrease the probability of a vehicle leaving the roadway was classified as accident potential reducing and any countermeasure designed to affect the vehicle's off-road travel characteristics was classified as accident severity reducing.

8.9.1.1 Accident Potential Reducing Countermeasures

Remedial treatments designed to decrease the probability of a vehicle leaving the roadway will assist the driver in maintaining vehicle control by improving both the roadway design features and the human factors characteristics at the hazardous locations. Countermeasure features would be expected to decrease the accident potential at locations where implemented by improving:

- <u>Visual features</u> that delineate the roadway proper, isolated hazardous roadway locations, extended roadway sections having substandard geometric conditions, or other hazardous extraordinary roadway conditions.

- <u>Aural features</u> that aid to awakening and alerting the fatigued and unattentive driver to potentially hazardous conditions by creating a noise or vibration.

- <u>Roadway surfaces</u> that provide the driver with additional pavement friction and/or additional roadway width at hazardous locations to allow a greater margin for error at the hazardous location.

- <u>Roadway alignments</u> so that geometrically substandard roadway sections can be eliminated from the roadway system, thus, eliminating the need for the driver to both recognize and make the correct driving corrections to traverse the substandard area.

Specific countermeasure treatments which were identified to reduce the accident potential at hazardous locations are listed in Table 8-57. The countermeasures are identified as primarily offering human factors improvements or as offering a geometric design improvement.

TABLE 8-57 ACCIDENT POTENTIAL REDUCING COUNTERMEASURES

Human Factors Improvement		Geometric Design Improvement
Visual		Surface Treatment
centerlines	warning signs	repave
lane lines	regulatory signs	deslick
edge lines	hazard signs	groove
lane delineators	pavement color	superelevation adjustment
roadway delineators	shoulder color	
hazard delineators	pavement markings	Widenings
shoulder markings		lane widening
		shoulder widening
Aural		Realignment
rumble strips	rumble edge lines	horizontal adjustment
textures shoulders	rumble lane lines	vertical adjustment
textured pavement		

8.9.1.2 Accident Severity Reducing Countermeasures

Countermeasure improvements undertaken in the roadside area are implemented to protect the occupants of vehicles leaving the road either by reducing the danger presented by roadside objects which the errant vehicle could strike or by allowing the driver of the errant vehicle additional area with which to regain control of his vehicle. Accident severity can be reduced through countermeasures in several ways:

- Roadway improvements can be implemented to improve vehicular departure characteristics.

- Roadside obstacles can be removed to eliminate the hazard caused by the obstacle's presence.

- Protective devices can lessen severity by interposing less hostile obstacles.

- Roadside obstacles can be relocated to a less hazardous location.

- Roadside obstacles can be redesigned to present a lessened hazard.

- Roadside areas between the obstacle and the shoulder can be improved to give the errant driver greater opportunity to control the vehicle and, thus, a greater chance of avoiding the obstacle.

Table 8-58 is used to both list the hazardous roadside condition and the countermeasures which would lessen the hazard associated with the condition. Roadway countermeasures which would affect the roadway departure angle have previously been listed in Table 8-57.

TABLE 8-58 ACCIDENT SEVERITY REDUCING COUNTERMEASURES

Hazardous Condition	Countermeasure(s)
Roadside Section	
Ditch	reshape, enclose, protective barrier
Sideslope	flatten, protective barrier
Sideroad (driveway)	reshape, flatten sideslope
Ground	regrade
Roadway Element	
Narrow bridge	widen bridge, provide attenuators, delineate bridge ends
Substandard parapet	reconstruct parapet
Guardrails present	evaluate need
Substandard guardrail present	evaluate need, improve to present standards of end treatment, post spacing, beam strength, run length, distance between runs
Roadside Element	
Signing	relocate, improvement to breakaway design
Poles	relocate, bury lines, improve to breakaway design
Culverts	cover, extend
Natural Features	
Trees	remove
Small trees, brush	evaluate their protective potential
Rock(s)	remove, protect with barrier

The countermeasures listed in Table 8-58 are applicable to roadside obstacles frequently encountered in the study's accident sample. They represent the relatively low cost improvements which could be implemented without additional right-of-way acquisition and within the limited rights-of-way typically found on many rural highways carrying relatively low traffic volumes.

8.9.2 Countermeasure Costs

To facilitate comparison of the countermeasures listed in Table 8-57 and 8-58, both construction cost and maintenance cost estimates were made for the listed countermeasures. The cost estimates were developed from several information sources to portray accurate countermeasure costs at 1976 price levels. The two primary sources utilized for the estimates were the Unit Bid Price tabulations obtained from the accident study states and personnel within the maintenance and operations sections of several state highway departments.

In developing construction costs, basic bid items used in construction were identified. For each countermeasure improvement, the various bid items used in constructing the improvement were quantified and an estimated contract cost for the improvement was determined. Since most improvement costs can be expected to vary considerably depending on the amount of improvement required to protect locations of varying length with varying heights and widths, a range of costs was determined for each countermeasure to depict a reasonable cost estimate which can be expected for each improvement.

In addition to the construction costs necessary to implement a countermeasure, maintenance costs required to keep the countermeasure in service must be accounted for if an accurate countermeasure cost is to be made. These maintenance costs include cost estimates for replacement, repair, and cleaning of the countermeasure improvement on an annual basis.

Quite often construction costs were found to vary as much between areas of a state as between states. Roadway item costs in large metropolitan areas or encompassing state highway districts were usually significantly higher than in less populous areas of a state. Additionally, unit prices involving large quantities of an item were normally lower than unit prices for small quantities.

Measures of maintenance costs are less precise than measures of construction costs - especially when tied to a particualr item. Maintenance forces may maintain several roadway items during a routine patrol that are not sorted in costing records. Budgets are often set to apportion work to specific maintenance routines (mowing, patching, cleaning drainage facilities) based on available funds. In recent years, these routines have been curtailed due to both monetary constraints and the expanding roadway mileage. Maintenance cost information is usually based on budgeted levels of effort and often reflects available funding rather than the actual costs required for proper maintenance.

Countermeasure improvements, once installed, usually must be maintained. The countermeasure installation may inhibit other maintenance routines - delineator cleaning vs. roadside mowing would be an example. Even though the maintenance costs of safety features cannot be estimated as accurately as the installation costs, the maintenance costs and problems for the countermeasures must be evaluated. It would appear desirable not to use a device which cannot be properly maintained.

Ranges of unit bid prices for the basic rural roadway construction bid items are listed in Table 8-59. A typical unit price which could be expected is also listed. These unit prices are those associated principally with general roadway construction contracts where major item quantities are involved. Bid prices for smaller item quantities, needed to construct spot improvements, could be up to two or three times higher than the prices tabulated.

TABLE 8-59 ORDER-OF-MAGNITUDE UNIT BID PRICES FOR RURAL ROAD CONSTRUCTION ITEMS

Item	Price Range	Typical in Roadway Quantities
Clearing and Grubbing	$500-$2,000/acre	$1,000/acre
Excavation - Ditching, Shaping or Special Removal	$2-$3/cu.yd.	$2.50/cu.yd.
Earthwork - Excavation or Borrow Compacted in Place	$0.50-$2/cu.yd.	$1.25/cu.yd.
Excavation - Rock(s)	$3-$6/cu.yd.	$5/cu.yd.
Crushed Rock - Base Course	$2-$6/ton	$5/ton
Selected Chips - Surface Texture and Contrast	$8-$16/ton	$12/ton
Tack or Seal Coat	$0.50-$1/gal.	$0.75/gal.
Asphalt Concrete - Base Course	$6-$18/ton	$12/ton
Asphalt Concrete - Surface Course	$8-$20/ton	$15/ton
Portland Cement Concrete - 8 inch Base Course	$3-$6/sq.yd.	$5/sq.yd.
Portland Cement Concrete - 8 inch Surface Course	$4-$8/sq.yd.	$6/sq.yd.
Class A Concrete - Drainage Structure	$75-$150/cu.yd.	$125/cu.yd.
Reinforcing Steel - Drainage Structure	$0.25-$0.50/lb.	$0.35/lb.
Seeding - Including Soil Preparation	$500-$1,000/acre	$750/acre
New Highway Bridges	$30-$60/sq.ft.	$45/sq.ft.
Widen Highway Bridges	$50-$80/sq.ft.	$60/sq.ft.
Miscellaneous and Contingencies as a Percent of the Above	15%-30%	20%
Engineering as a Percent of the Above	10%-20%	15%

Order-or-magnitude costs for installing and maintaining the countermeasures tabulated in Table 8-57 and 8-58 together with the estimated countermeasure service life are listed in Table 8-60. The installation costs reflect total in-place costs - assuming the improvements are implemented in significant quantities. For example, the estimates for center and edge lines reflect costs associated with a continuing maintenance force routine or contracts covering extensive road mileage. Guardrail costs would involve several hundred feet of installation. Shoulder or surface treatment costs are typical for projects improving several miles of roadway. Similarly, the maintenance costs are generally associated with routine or scheduled maintenance.

8.9.3 Current Practice and Problems with Countermeasures

In November 1975, a questionnaire was distributed to all state highway agencies requesting information on the "Application of Roadway Protective Devices on State Maintained Highways". The purpose of this questionnaire was to determine current state practives and maintenance problems for state-or-the-art highway safety items. Results of this questionnaire served as a primary input in determining the feasibility of safety solutions to the single vehicle, run-off-road accident problem. Forty-nine states completed and returned the questionnaire.

The responses of these 49 states were compiled and are shown in Table 8-61. Countermeasures with 30 or more responses are circled and associated maintenance problems cited by at least 50 percent of the agencies using the device are boxed. Some of the common problems and comments expressed by the state agencies are summarized below.

- <u>Pavement edge lines</u> were used by all states. Twenty-three of the states experienced durability problems, with durability in snow areas commonly being cited.

TABLE 8-60 ORDER-OF-MAGNITUDE COUNTERMEASURE COSTS

INSTALLATION - SERVICE LIFE - ANNUAL MAINTENANCE

Countermeasure	Installation	Service Life	Annual Maintenance
Center Line--4 inch paint	$75/mile	1/2-2 yrs.	None
Edge Line--4 inch paint both edges of pavement	$200/mile	2-4 yrs.	None
Delineators--single white both sides of roadway (1)	$5,000/mile	6-8 yrs.	$300/mile (2)
Small sign			
--install	$150/each	6-8 yrs.	$5/each (3)
--relocate	$ 50/each	Infinite	N.A.*
Guard Rail, blocked out W-beam (4)			
--install	$10/lin.ft.	20 yrs.	$1/lin.ft. (5)
--relocate	$ 4/lin.ft.	Infinite**	N.A.
--block out existing	$ 4/lin.ft.	Infinite	N.A
--relocate and block out	$ 6/lin.ft.	Infinite	N.A.
--install terminals and anchorage	$500/each	20 yrs.	$25/each (5)
--install bridge end or abutment connections	$500/each	20 yrs.	$25/each (5)
Textured Shoulder--seal and chip existing asphalt shoulders (estimated for 6 feet both sides)	$6,000/mile	5-10 yrs.	N.A.
Rumble Shoulder--develop corrugations on 3 to 4 asphalt edge strip build on existing unpaved shoulder (6)	$50,000/mile	20 yrs.	N.A
--(rumble corrugations included in above)	$ 5,000/mile	20 yrs.	N.A.
Pavement Friction--2 inch asphalt overlay (7)	$30,000/mile	20 yrs.	N.A.
Pavement Shoulder Contrast--(see Textured Shoulder)	$ 6,000/mile	5-10 yrs.	N.A
Tree Removal, 6 inch diameter or greater			
--spot location	$500/each	Infinite	None (8)
--scattered, say 20 plus/mile	$150/each	Infinite	None (8)
--forest @ 100 ± per acre	$6,000/acre	Infinite	$200/acre (9)
Sapling and Brush Removal			
--clear, grub and seed	$3,000/acre	Infinite	$200/acre (9)
Mail Box			
--replace with ridedown post	$150/each	20 yrs.	N.A.
--relocate 12 feet from pavement edge including postal vehicle platform (10)	$2,500/each	20 yrs.	N.A.
Fencing			
--replace with woven wire fence (11)	$ 3/lin.ft.	20 yrs.	N.A.
--replace with chain link fence (11)	$10/lin.ft.	20 years	N.A.
--relocate, woven wire or barb wire fence	$ 2/lin.ft.	Infinite	N.A.
--relocate chain link fence	$ 4/lin.ft.	Infinite	N.A.
Utility Poles			
--relocate power			
--relocate telephone			
--relocate combined			
--bury power			
--bury telephone			
--easement for relocation outside right-of-way, etc.			

*-Indicates <u>not applicable</u>. Either there are <u>no</u> or <u>negligible</u> additional maintenance costs or the costs cannot be meaningfully measured from existing information. Some reduction in maintenance may be expected for objects relocated further from the traveled way.

**-An infinite service life was assumed for objects removed or relocated. Relocation is generally associated with the labor for a one-time activity rather than the physical life of the object.

TABLE 8-60 FOOTNOTES

(1) Based on 500 delineators per mile. Approximates 80 percent tangent alignment with 300 foot spacing and 20 percent curved alignment with 100 foot average spacing. Installation cost @ $10 per each.

(2) Estimated for routine cleaning delineators every 2 years @ $0.40 each (25 per hous @ $10 per hour maintenance force cost) and replacing bent and knocked down units, damaged at a rate of 4 percent (1 in 25) of the units per year. Replacement cost @ $10 each. Replacement expected to be at a higher rate in heavy snow areas (say 1 in 20 per year). Vandalism, mowing, and snowplow operations as well as collisions are factors associated with maintenance replacement.

(3) Estimated for routine field cleaning of sign faces every 2 years @ $1.60 each and replacing or refurbishing vandalized and knocked down signs, damaged at a rate of 4 percent per year. Replacement or refurbishing estimated @ $100 per sign.

(4) Blocked out W-beam is becoming the most predominantly used guardrail device. Cable and box beam, the other common guardrails, appear to be used principally to reduce snow problems - less suseptible to creating snow drifts and afford easier snow plow operations than blocked out W-beam. Installation costs and service life for cable and box beam guardrail are of similar magnitude of those of the blocked out W-beam. Maintenance costs, however, may be expected to be higher for cable and box beam due to the larger deformation and greater length of damage when struck.

(5) Approximated on the need to straighten and/or replace damaged guardrail elements assuming about 5 percent of its exposed length is deformed or knocked out annually together with cleaning and delineation upkeep. Replacement and repair costs estimated to be equal to cost of installation.

(6) Essentially equivalent to constructing a 3- to 4-foot asphalt shoulder surface adjacent to the traveled way and stamping or rolling-in corrugations at 10-foot intervals during the finishing process. The cost estimate includes reconstruction of 8-foot subgrade shoulders on an existing roadbed that is about 40 feet wide. The treatment will also eliminate shoulder drop-off or rutting at the traveled pavement edge. The paved strip may only partially cover the shoulder width available for disabled vehicles. The corrugations may be incorporated in resurfacing projects as well as widening and resurfacing improvements.

(7) Includes leveling of depressions (rutting or settling of surface over the years) that has created ponding. The principal purposes from the standpoint of a friction improvement is to eliminate water standing on the roadway as well as improve its texture when wet. Quite often resurfacing is also undertaken to upgrade a structurally unsound surface (raveled, cracked, bumpy, etc.). Costs for additional leveling and patching needed due to substantial surface deterioration would raise the cost estimate.

(8) Assumes existing maintenance routine - mowing or other would preclude regrowth of the trees.

(9) Estimated for annual mowing or other maintenance of cleared areas to preclude tree or brush growth.

(10) Includes widening and stabilizing the shoulder to afford a 12-foot pull off area for the postal delivery vehicle. Estimate based on a nominal 9-foot widening of the shoulder at the mailbox site, together with some taper treatment. Annual maintenance of the extra shoulder width assumed to be negligible.

(11) Assumes replacement of timber or wooden fences. Stone, mason, or other more substantial fencing replacement would cost more to remove.

TABLE 8-61 APPLICATION OF ROADWAY COUNTERMEASURES ON STATE MAINTAINED HIGHWAYS

ROADWAY PROTECTIVE DEVICE					CURRENT APPLICATION												MAINTENANCE PROBLEMS								
					INTERSTATE			FEDERAL AND PRIMARY			FEDERAL AID SECONDARY			NON-FEDERAL AID											
	NOT USED	USED-WARRANTS ESTABLISHED FOR USE	USED-USAGE DETERMINED BY INFORMAL POLICY	USAGE NOT INDICATED	COMMON USE	SPECIAL USE ONLY	NOT USED	COMMON USE	SPECIAL USE ONLY	NOT USED	COMMON USE	SPECIAL USE ONLY	NOT USED	COMMON USE	SPECIAL USE ONLY	NOT USED	NONE	ITEM DURABILITY	REPLACEMENT COST	VANDALISM	SPARE ITEM INVENTORY REQUIREMENTS	EXPENSE FOR ROUTINE MAINTENANCE	NOT STATED	NOT USED	EXPERIMENTAL USE ONLY
PAVEMENT EDGE LINES	0	34	13	2	48	0	1	45	4	0	36	12	1	21	23	5	13	23	17	0	0	16	0	0	0
DELINEATORS (BY LOCATION)																	3	10	21	22	6	29	0	1	0
CURVES ONLY	13	22	9	5	20	0	29	16	18	15	17	17	15	0	0	46									
TANGENTS AND CURVES	1	30	16	2	42	2	5	13	26	10	6	25	16	6	29	12									
GUARDRAIL																									
W-BEAM	28	11	6	4	9	3	37	10	8	33	11	6	32	11	10	29	5	1	6	0	5	10	1	28	0
BLOCKED OUT W-BEAM	1	41	8	1	43	2	4	42	5	2	35	12	2	30	10	6	7	2	25	1	12	16	4	1	0
BOX BEAM	25	13	11	0	8	17	26	5	18	28	4	7	38	4	6	37	5	1	14	0	6	8	3	25	0
W-BEAM AND RUB ROLL COMBINATION	28	6	13	1	10	12	27	6	13	28	4	13	32	4	11	34	4	1	13	0	7	5	3	26	0
CABLE	28	13	6	2	6	7	34	10	6	31	12	6	29	10	6	31	6	2	7	1	6	7	1	26	0
CHAIN LINK FENCE	35	5	6	1	5	7	37	2	11	36	1	4	44	2	5	42	2	1	5	3	3	4	1	35	0
THRIE BEAM	42	1	4	2	2	3	44	1	4	44	0	2	47	1	3	45	0	0	2	0	2	1	4	42	5
OTHER ________	44	3	0	2	3	0	46	4	1	44	3	1	46	2	2	45	1	0	3	0	0	2	1	44	0
GUARDRAIL POST																									
WEAK STEEL	34	10	5	0	6	5	38	7	6	36	7	3	39	5	3	41	5	2	5	0	6	3	2	34	1
STEEL	7	23	15	4	30	6	10	30	10	6	26	10	13	24	8	17	20	0	10	0	5	10	8	7	0
WEAK WOOD	41	4	2	2	3	3	43	4	2	43	4	3	42	4	4	41	2	1	1	0	4	4	1	41	1
WOOD	6	27	12	2	35	3	11	35	4	10	34	5	10	32	6	11	12	4	15	0	6	6	6	6	0
CMB OR NEW JERSEY BARRIER																									
MEDIAN (BY LOCATION)	3	23	21	2	28	16	4	16	24	7	8	21	22	5	17	27	38	1	2	0	2	1	5	3	1
BRIDGE PARAPET	8	24	14	3	29	12	6	27	13	8	21	11	17	17	13	16	36	0	1	0	0	0	4	6	0
SHOULDER	18	4	27	2	2	29	18	3	26	20	1	18	29	1	18	30	26	0	1	0	0	0	6	16	0
POLES (BREAKAWAY)																									
SHEAR BASE LUMINAIRE	12	25	10	2	29	7	13	28	6	12	22	8	16	16	8	22	16	1	13	0	6	3	3	12	1
SLIP BASE LUMINAIRE	28	15	4	2	15	5	29	15	5	28	11	5	32	10	5	34	6	0	5	0	2	1	6	28	0
SLEEVE BASE LUMINAIRE	44	3	0	2	3	0	46	4	0	45	4	1	44	3	0	46	2	0	2	0	0	1	1	44	1
WOODEN UTILITY	24	4	11	10	5	3	41	13	8	30	14	6	27	17	7	25	10	0	3	0	0	2	10	24	0
Other ________	38	5	3	3	7	4	38	7	3	39	8	0	41	8	2	41	2	0	4	0	3	1	3	38	1
SIGN POSTS																									
HINGE JOINT W/SLIP BASE	4	38	8	1	41	3	5	26	16	5	17	16	18	14	13	22	16	4	10	0	13	10	4	4	0
SLIP BASE	24	19	6	0	20	3	26	13	10	26	8	11	29	6	11	32	12	1	4	0	8	6	3	24	0
NOTCHED WOODEN	32	15	2	0	11	5	33	15	1	33	13	2	28	10	3	38	8	1	4	0	3	5	2	32	0
FRACTURE JOINT A-FRAME	46	0	2	1	0	1	48	0	2	47	1	2	46	0	2	47	2	0	0	0	0	0	1	48	2
CRASH ATTENUATING DEVICES																									
STEEL DRUM	27	7	14	1	5	18	28	5	13	31	4	7	38	3	5	41	2	5	11	1	12	6	1	27	6
PITCH	4	13	29	3	16	26	5	17	25	7	6	15	26	5	14	29	4	10	29	10	25	13	2	4	3
HI-DRO CELL	10	10	28	1	13	26	10	12	25	12	6	13	30	5	12	32	11	3	18	2	17	12	3	10	3
LIGHTWEIGHT CELLULAR CONCRETE	41	1	7	0	0	5	43	0	5	43	0	4	45	0	2	47	2	1	1	0	1	2	4	41	4
SHRUBBERY	40	0	6	1	2	8	41	2	5	42	1	4	44	1	3	45	2	0	1	0	0	4	3	40	1
OTHER ________	40	3	3	3	1	5	43	1	8	42	1	2	46	1	1	47	0	1	2	2	3	2	5	40	5
PAVEMENT TREATMENTS																									
GROOVING	23	5	20	1	5	21	23	4	21	24	2	18	29	2	13	34	10	13	3	0	0	0	3	23	7
ASHPHALT OVERLAY	5	17	24	3	16	14	7	31	12	8	28	10	11	27	6	14	20	7	8	0	0	7	8	5	1
ASHPHALT OVERLAY USING EXPANDED AGGREGATE	42	2	5	0	1	5	43	1	8	42	1	6	42	1	5	43	3	1	1	0	0	1	3	42	7
ASPHALTIC DESLICKING	32	5	11	1	3	14	32	5	11	33	4	10	35	4	8	37	3	5	1	0	0	5	8	32	4
OTHER ________	41	2	5	1	3	4	42	3	3	43	3	3	43	2	2	45	2	4	2	0	0	0	2	41	3
MISCELLANEOUS, NEW, OR NOVEL MEANS OF ALERTING DRIVERS TO HAZARDS (SUCH AS)																									
CHANGEABLE MESSAGE SIGNS	17	7	22	3	1	26	22	3	21	25	3	15	31	3	12	34	9	4	2	1	3	10	8	17	7
BEACONS	10	14	22	3	2	22	25	10	28	11	6	29	11	5	24	16	18	1	2	4	1	6	8	10	1
RUMBLE STRIPS	12	2	33	2	3	18	29	2	31	15	2	29	18	2	25	22	10	15	4	1	0	4	6	12	5
TEXTURED PAVEMENT	38	2	6	0	2	6	41	1	7	41	1	5	43	0	4	45	6	2	0	0	0	0	0	38	4
TEXTERED SHOULDERS	26	4	14	5	13	9	27	7	13	28	8	8	35	5	5	38	11	4	4	0	0	6	4	26	3

LEGEND:

33 – NUMBER OF STATE'S RESPONSES

◯ – 30 OR MORE RESPONSES

▭ – 50% OR MORE OF THE AGENCIES USING THE DEVICE CITED MAINTENANCE PROBLEMS

- Delineators were used by all states except Alaska. Twenty-nine of the states cited expense for routine maintenance as a problem. Reasons given for this problem were vandalism, extra mowing effort required, and vehicular destruction of the delineators.

- Guardrail replacement costs are mentioned as a problem by many users of blocked-out W-beam, box beam, and W-beam combined with rub rail. Blocked-out W beam was used by the largest number of states (47); box beam by the second largest (24); and cable by the third largest (21). Cable had the greatest percentage of users experiencing no maintenance problems, followed by box beam; W-beam ranked sixth. However, three states stated that cable was the most expensive type of guardrail to maintain and four other states mentioned that cable was being phased out due to high maintenance costs. Use of a W-beam straightening machine to repair damaged W-beam guardrails was cites as a means of greatly reducing maintenance costs.

- GM or New Jersey Barrier was the easiest item to maintain - well over 50 percent of the users reported no maintenance problems. In New York, breakage was reduced by increasing the stem thickness to nine inches in places where breakage was a problem. Drifting snow was the most commonly mentioned problem associated with this device.

- Breakaway pole users appeared to favor the shear base luminaire. This type of breakaway pole had both the greatest number of users and the greatest percentage of users with no maintenance problems. Replacement cost and inventory requirements were the two most common maintenance problems.

- Sign post users favored the hinge-joint, slip-base type of post assembly. However, the type ranked third under maintenance problems because of replacement costs, inventory requirements, and routine maintenance expenses. The slip-base assembly was less difficult to maintain, but wind-induced slippage of the flange plates was mentioned five times as a problem.

- Crash-attenuating devices commonly used were the Fitch (45 states), Hi-Dro Cell (39 states), and steel drum (22 states). Many states using these attenuators experienced maintenance problems such as replacement costs, inventory requirements, and routine maintenance expenses. The Hi-Dro Cell users experienced fewest maintenance problems. Both Fitch and steel drum users more frequently mentioned replacement cost problems, and Fitch users cited additional problems with vandalism and durability.

- Pavement treatments most widely favored were the standard asphalt overlay and pavement grooving. Excessive wearing of the pavement grooves due to the use of studded snow tires has caused four states to drop this treatment as long as studded tires are permitted.

Many miscellaneous roadway devices were mentioned. Changeable message signs were used to indicate reversible lanes; to indicate a following-too-closely warning; to indicate lower speed limits; and to show other different message groupings. Beacons were used on warning signs, at roadway transition sections, at intersections, and at low clearance underpasses. Rumble strips were generally mentioned as being used when other remedial measures were ineffective. Textured pavement was generally used instead of rumble strips for shoulder treatments. Maintenance difficulties with textured pavement were commonly mentioned.

8.9.4 Countermeasure Needs

The findings of this study represent more of a collection of facts about single vehicle accidents on rural roads than warrants for countermeasures. Furthermore, it is clear that great care is required in the establishment of warrants. This stems largely from the large number of variables which may interact to influence the occurrence of accidents and their resultant severity.

In order to avoid overstepping the implications of the data, the following discussion is limited to two factors. The first is geometric alignment which was clearly shown to influence the occurrence of accidents. The second is the object struck which had important effects on severity.

8.9.4.1 Geometric Alignment

Countermeasure applications to correct for overrepresented horizontal alignment characteristics include treatments for horizontal curvature locations, especially left curve locations. Analysis of the data sample suggest that:

- <u>Delineation treatments</u> indicating horizontal curve presence should be emphasized due to the number of accident locations on a horizontal curve and the high frequency of accident locations within 400 feet of the curve's beginning. Overrepresentation of curve accident locations on left curves rather than right curves. furthermore suggest that emphasis should be placed on treatments indicating a left curve alignment.

- <u>Pavement surface treatments</u> when used to increase surface friction should be extended well beyond the curve end to be effective.

When vertical alignment characteristics are combined with horizontal alignment characteristics, additional countermeasure applications are suggested:

- Intensive delineation treatments when horizontal curves are combined with either crest vertical curves or a downgrade; vertical alignment should be emphasized since this condition appears considerably more hazardous than normal.

- Pavement surface friction treatments should be extended to at least 600 feet past a horizontal curve end if a downgrade alignment is present.

- Advisory speed limits posted for horizontal curves should be lowered when downgrade vertical alignments are present.

- Additional signing warning of the downgrade-horizontal curve condition should be developed.

In future design standards, the practice of placing horizontal curves within 600 feet of a crest vertical curve should be discouraged. Additionally, particular attention should be given to designs at locations requiring horizontal curves to the left and downgrade vertical alignments.

8.9.4.2 Roadside Objects

Roadside features - geometric shape and obstacles - are the principal inputs in looking at possible countermeasures to reduce accident severity. Frequency distributions of objects struck in primary impacts are given in Table 8-62. The injury severity associated with the more frequent of these objects, ranked by severity, is given in Table 8-63. Note that primary impacts, rather than all impacts, are used because the injury severity is associated with the principal impact so that injury severities for the secondary impacts are not known. Both rollovers and nonrollovers are included.

TABLE 8-62 OBJECTS STRUCK - PRIMARY IMPACT

	Frequency	%
Terrain		
Ground	3,617	46.6
Ditch	387	5.0
Embankment	435	5.6
Culvert	244	3.1
Field Approach	76	1.0
Other, Unknown	65	0.8
	4,824	62.1
Posts, Poles		
Small Sign Post	76	1.0
Wooden Utility Pole	644	8.3
Other Wooden Pole	28	0.4
Metal Lite Std. - Breakaway	1	0.0
Metal Lite Std. - NB*	8	0.1
Metal Lite Std. - Unk. - B	3	0.0
Metal Sign Sup. - B*	9	0.1
Metal Sign Sup. - NB	11	0.1
Metal Sign Sup. - Un Unk. - B.	13	0.2
Metal Other - NB	3	0.0
Metal Other - Unk. - B	1	0.0
Concrete Base - Sign	2	0.0
Concrete Base - Other, Unknown	1	0.0
Delineator	20	0.3
Other, Unknown	11	0.1
	831	10.6
Natural Objects		
Tree	709	9.1
Trees, Brush	281	3.6
Rock(s)	68	0.9
Other, Unknown	19	0.2
	1,077	13.8
Fixed Objects		
Fence	338	4.4
Mailbox	34	0.4
Hydrant	2	0.0
Junction Box	4	0.0
Building	36	0.5
Other, Unknown	79	1.0
	493	6.3

	Frequency	%
Temporary Objects		
Traffic Barrels	3	0.0
Construction Barriers	2	0.0
Construction or Other Equipment	3	0 0
Construction Excavation	1	0.0
Other, Unknown	2	0.0
	11	
Permanent Barriers		
Guard Rail	294	3.8
Concrete Barrier	4	0.1
Guard Post(s) - Wood	17	0.2
Guard Post(s) - Concrete	5	0.1
Guard Post(s) - Other, Unknown	4	0.1
	324	4.3
Attenuator		
Fibco	1	0.0
Other, Unknown	1	0.0
	2	
Road Structure		
Tunnel - Int. Wall	1	0.0
Underpass - Int. Support or Wall	5	0.1
Underpass - Other, Unk.	3	0.0
Underpass - O, Unk.	1	0.0
Bridge/Overpass-Side Rail	88	1.1
Bridge/Overpass Entrance	88	1.1
Bridge/Overpass Other, Unknown	4	0.1
Retaining Wall	10	0.1
	200	2.5
Other, Unknown	175	---
TOTAL	7,937	

*Not Breakaway

**Breakaway

TABLE 8-63 DRIVER INJURY SEVERITY FOR SELECTED ROADSIDE OBJECT CONTACTS - PRIMARY IMPACTS

Object Struck	Primary Impacts			
	No Injury	Injury	Fatal	Total
Bridge/Overpass Entrance	29 (33.0)	46 (52.3)	13 (14.8)	88
Field Approach	26 (34.7)	48 (64.0)	1 (1.3)	75
Tree	244 (36.6)	390 (58.5)	33 (4.9)	667
Culvert	99 (43.2)	120 (52.4)	10 (4.4)	229
Ground (rollovers)	834 (43.1)	1,020 (52.7)	81 (4.2)	1,935
Embankment	192 (47.4)	200 (49.4)	13 (3.2)	405
Wooden Utility Pole	315 (52.9)	274 (46.0)	7 (1.2)	596
Ground (non-rollovers)	82 (53.6)	69 (45.1)	2 (1.3)	153
Bridge/Overpass Side Rail	44 (53.7)	37 (45.1)	1 (1.2)	82
Rocks	40 (55.6)	32 (44.4)	0 (0.0)	72
Ditch	215 (58.6)	151 (41.1)	1 (0.3)	367
Trees, Brush	163 (63.9)	87 (34.1)	5 (2.0)	255
Guard Rail	203 (69.5)	84 (28.8)	5 (1.7)	292
Fence	255 (78.7)	68 (21.0)	1 (0.3)	324
Small Sign Post	61 (80.3)	14 (18.4)	1 (1.3)	76
Mailbox	26 (86.7)	4 (13.3)	0 (0.0)	30

The listing of objects struck affords a sound basis for selecting countermeasures to be considered in dealing with roadside obstacles encountered on rural non-freeway type highways (since 85% of all the accidents occurred on these road types). The roadside contour - including ditches, embankments, culverts, and ground - accounted for 62.1 percent of the primary impacts, posts and poles 10.6 percent, naturally occurring objects (trees, rocks, etc.) 13.8 percent, fixed objects (fences, mailboxes, etc.) 6.3 percent, guard rails 4.3 percent, and road structures (bridge abuttments, etc.) 2.5 percent.

As is to be expected, objects associated with urban facilities such as traffic signal poles, light poles, large size poles, curbs, underpass piers or abuttments were rarely encountered. Drainage elements such as culverts, head walls, and drainage inlets were also rarely hit, possibly explained by the fact that many of the rural roads studied were built several years ago under less modern design standards. This means that (1) large drainage schemes were not required because there is significantly less roadway surface water to dispense from two-lane pavements often with unpaved shoulder than from modern multi-laned facilities with full shoulder pavements and (2) vertical alignments more closely followed existing terrain and thus, require less fill at cross drains, thereby reducing the potential use of head walls to shorten culverts.

As a basis for evaluating possible countermeasures to roadside obstacles, only objects which were hit more frequently than one percent of the time are considered. Table 8-64 lists these objects together with their possible countermeasures. Note that their relative severity is also given as there is little point in terms of prioritizing implementation, to consider protecting objects that are not injury producing. Assuming that guard rails provide optimum protection and that they are installed to protect errant vehicles from striking a more substantial object, then an injury frequency of about 30 percent appears to be the level below which it is not feasible to provide additional protection. Obviously there are safety devices which could provide higher levels of protection, for example impact attenuators, but at this low level of injury frequency they would be unlikely to prove cost-effective.

TABLE 8-64 ROADSIDE OBJECTS MOST COMMONLY HIT BY DEPARTING VEHICLE, FREQUENCY OF DRIVER INJURY, AND POSSIBLE COUNTERMEASURES

Object Struck	Relative Frequency Primary Impact	Injury Frequency Primary Impact	Possible Countermeasures
Terrain			
Ground	46.6	56.1	Predominately rollover; spot improvements to reduce tripping
Ditch	5.0	41.4	Reshape, flatten slope
Embankment	5.6	52.6	Guard rail
Culvert	3.1	56.8	
Field Approach	1.0	65.3	
Post, Poles			
Wooden Utility Pole	8.3	47.2	Relocate, underground
*Small Sign Post	1.0	19.7	Snap-off post
Natural Objects			
Tree	3.6	36.1	Remove
*Trees, Brush	3.8	30.5	Clear
Rocks	0.9	44.4	Remove, guard rail
Fixed Objects			
*Fence	4.4	21.3	Relocate, weaker fencing
*Mailbox	0.4	13.3	Snap-off post
Barriers			
Guard rails	3.8	30.5	Injury severity low - removal vs. protection afforded
Road Structures			
Bridge/Overpass - Side Rail	1.1	46.3	Widen guard rail, attenuator, delineator
Bridge/Overpass - Entrance	1.1	67.1	

*Injury severity of these objects is unlikely to be sufficient to warrant countermeasure treatment.

9. DISCUSSION

The intent of this report was to present reference material on hazards associated with rural roads. Detailed information was presented on road and roadside factors influencing how departures occur, off-road vehicle behaviors, impact characteristics, and resultant injury. Each section is concluded with a summary of findings to which the reader is referred for specifics.

In this section, a brief summary of major findings is given. It is followed by some general considerations for the highway engineer. Finally, recommendations for further research are discussed.

9.1 Major Findings

9.1.1 Factors Influencing Injury

As might have been anticipated, the major determinants of injury were those factors directly associated with vehicle impacts. The single greatest determinant of injury was occupant ejection from the vehicle. Following that were impact characteristics. The injury rate was high for compound or extended rollovers; it was low for nonrollover impacts in which the vehicle went through or over the object struck, or otherwise continued moving after impact. The injury rate was high if the object struck in the primary impact was nonyielding (e.g., bridge or overpass entrances, single trees, field approaches, culverts) and low for more yielding objects (e.g., small sign posts, fences, guardrails, and small trees or brush). Injury rates increased with increasing impact speed. Finally, in nonrollover impacts, injury rates were higher for frontal impacts than for other impact areas.

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* There is a summary at the conclusion of each of the separate special studies.

Among other factors studied, those having the greatest effect upon injury were, in descending order: drinking status, pole offset, restraint use, horizontal curve length, predeparture maneuver, departure angle, driver condition, road condition, and distance from the origin of tire marks to the departure point; these factors all had contingency coefficients of 0.10, or greater. Of these nine variables, three were wholly driver determined (drinking status, driver condition, and restraint use), three were behavioral in nature reflecting interactions between the driver and the roadway (maneuver, distance of tire marks, and departure angle), and three were roadway factors (road condition, pole offset, and curve length).

9.1.2 Road Alignment

9.1.2.1 Accident Occurrence

Among the accidents where horizontal alignment was known, over 40 percent occurred on curves. Since exposure information was not available, it cannot be documented that the accident rate was higher on curves than on tangents. However, since it was unlikely that 40 percent of the travel was on curves, it can be concluded that rates were higher on curves than on straight roads.

For undivided roads, the number of accidents on left curves was 61 percent higher than the number on right curves. Because every left curve is a right curve in the opposite direction, it is likely that the exposure to the two conditions was essentially equivalent. On this basis, the single vehicle accident rate on left curves was 61 percent higher than that on right curves.

Considering vertical alignment on undivided roads, there were 88 percent more accidents on downgrade tangents than on upgrade tangents. Using the same logic applied to horizontal alignment, this implies an 88 percent higher accident rate on downgrades.

Considering the combination of curves on up- or downgrades, exposure could be expected to be approximately equal for downgrades on left curves versus upgrades on right curves, and for upgrades on left curves versus downgrades on right curves. On this basis, the accident rate was almost three times greater for downgrades on left curves versus upgrades on right curves. For the remaining comparison, the accident rate was 32 percent higher for right curves on downgrades versus left curves on upgrades.

Horizontal curves were further indicted by the fact that accident frequencies were higher immediately after the curve than they were farther downstream. Similar results were found for vertical curves. Finally, results of the percent of horizontal curve traversed suggested an overrepresentation of problems originating at the beginning of the curve.

9.1.2.2 Injury Rates

Injury rates were found to be somewhat higher in accidents occurring on vertical curves, and to a lesser extent on tangent grades, relative to accidents on level roads. They were also higher in accidents on left curves than on right curves or straight roads. The higher injury rate on left versus right curves was attributed to the greater proportion of outside departures on left curves. The higher injury rate for outside departures was, in part, due to higher impact speeds, more impacts with trees and utility poles, and more frontal impacts.

For left curves, injury rates were lower if the degree of curvature exceeded eight degrees. In such instances, impact speeds were lower and there were fewer rollovers.

9.1.3 Road Fill and Ditches

Rollovers were more likely to occur among accidents on roads built on fill than on ditch cut roads. Among nonrollover impacts, it was found that ditches, embankments, and culverts were overrepresented for the ditch cut roads. Relatively more rollovers occurred with increasing fill height and ditch depth, with the exception that for ditches at least six feet deep, the proportion of nonroll impacts increased. The slope of fill and ditches had its primary effect on the proportion of departures with no impact; as slope increased, nonimpact departures decreased. There appeared to be distinct thresholds of slope and height at which these effects were evident; the reader is referred to Section 4 for details.

A separate analysis of ditch depth and injury showed the higher injury rate for deeper ditches was associated with a greater frequency of nonroll impacts with ditches, culverts, and field approaches. The injury rate was notably higher when the object struck was a deep, rather than shallow, ditch. It was also shown that part of the increased injury rate associated with accidents on roads with deep ditches was due to higher impact speeds.

9.1.4 Offsets for Nontraversable Roadside Borders

In comparison to small offsets, accidents occurring in the presence of large border offsets were characterized by a higher injury rate, higher impact speeds, more rollovers, and impacts farther from the road. An analysis in response to the unexpected increase in impact speeds for larger border offsets suggested that travel speeds were higher on roads with large offsets; this may have been due to the offset *per se* or to generally improved characteristics of roads with large offsets.

The higher injury rate in the presence of large offsets was mainly due to the higher impact speeds and the greater incidence of rollovers.

The frequency of colliding with wooden utility poles, which can be viewed as semi-traversable borders, decreased with increasing pole offset at a rate of approximately five percent for every six feet. The speed of impacts with poles decreased with pole offset, but only when it exceeded 24 feet. However, as with border offset, the injury rate in the presence of wooden utility poles increased with pole offset; the effect was greater than that for nontraversable borders.

9.1.5 Guardrails

The median angle of impact for guardrails was between nine and eleven degrees; however, the variation was very large. For example, at least fifteen percent of the impacts appeared to exceed 30 degrees. This suggests that guardrail standards testing could well be too limited if conducted only at one angle.

The injury rate for guardrail impacts was low relative to rollovers and nonroll impacts with most other objects. Nonetheless, guardrail performance was not as good as that desired. Forty-six percent of the guardrail strikes resulted in sudden stops, vaulting, or otherwise traveling through or over the guardrail. For primary impacts, injury rates were lower for wood post blocked W-beams than for similar guardrails with steel posts.

On the basis of limited information, it was suggested that small trees and brush might be an effective roadside barrier.

9.1.6 Miscellaneous Safety Features

If they were effective, pavement edgelines and reflective delineators could have been expected to reduce the frequency of nighttime accidents; they did not. However, the condition of the pavement markings at the time of the accidents was not known, and it is reasonable that many of the reflective delineators were located at high risk locations. Thus, the results were not conclusive.

Edgelines were also studied by comparing the likelihood of outside departures on left curves with and without edgelines present. Based on earlier discussions suggesting that many outside departures derived from insufficient awareness of the curve, it was thought that effective delineation would reduce the proportion of outside departures; results demonstrated edgelines were effective in this way.

Also tested in this way were centerlines, light conditions, and curve warning signs. Results showed fewer outside departures for daytime accidents and for accidents where centerlines were present. No such benefits were found for curve warning signs, but like delineators, they may have been placed at particularly hazardous locations.

Shoulder width was studied in several ways. It was not found to influence the likelihood of nonimpact departures or rollovers, nor did it have a significant effect on injury rate. Increased shoulder width did, however, result in fewer outside departures on left curves thereby suggesting that shoulders provide a useful buffer for moderately errant vehicles.

9.2 General Considerations

9.2.1 Roadway Characteristics and Injury

In order to obtain a simple measure of the relative influence of driver, road, behavioral, and off-road factors on injury, the proportion of variables which had a statistically significant relationship to injury was obtained for each group of factors. Of the eight driver related variables (including restraint use), seven, or 88 percent, had significant effects on injury. Of the nine event and departure variables, eight, or 89 percent, were significant. Of the 12 road characteristics (excluding weather), six, or 50 percent, had significant effects on injury, and of the 11 roadside factors, five, or 42 percent, were significant. Thus, while almost all of the variables largely under driver control were statistically significant, less than half of the variables primarily under the control of the highway engineer were.

This is not intended to encourage frustration in the design for safety of roads and roadsides. Although the driver-influenced variables bore stronger relationships to injury, they are far less susceptible to improvements than are road and roadside factors.

Perhaps the major point here is that every attempt should be made to discern those roadway factors which are of true importance to highway safety, to understand the mechanisms by which they achieve their effects, and only then to implement remedial activity. Some of the factors suggested by this study include the treatment of curves (particularly for traffic exposed to left curves), downslopes and vertical curves, offset effects, and the height of fill and ditches. In almost all instances, it appears that consideration of the driver and his habitual modes of operation, rather than stipulations of what he should do, is an essential requirement in designing for safety. This view is discussed further in the following.

9.2.2 Contrary Results

There was a class of findings which appeared to be contrary to the view that improved conditions are safer conditions. Examples include lower injury rates for snow covered roads, sharper curves, and small border and pole offsets. This is not to imply that there is reason to doubt the validity of such results, but rather to recognize their existence. Resolution of these problems calls for a consideration of the findings within a context which takes into account their effects on (1) injuries resulting from accidents, (2) accident generation, and (3) the quality of traffic flow.

A second point is raised by such findings. Each of them appears to reflect the adaptive capability of the driver who, to one extent or another, takes risk into account. The converse of this is that the better the roadway, the fewer the precautions taken by the driver. Experience with limited access roads implies that this can be a useful trade-off; high design standards have led to improved transportation and safety.

But what of lower volume roads where such expense is not justified? One approach is to help the driver to help himself. The findings regarding outside departures on left curves may be relevant here. These results, although they can be accepted only tentatively, suggest the driver was helped by centerlines and edgelines but not by curve warning signs. If this is verified, it suggests there is a need to determine what information the driver wants and how to present it to him. Assuming the pavement markings were no more conspicuous than the curve signs, it appears the drivers were more attentive to the pavement markings. The implication here is that the provision of information will be enhanced if it is done in ways which are compatible with drivers' information gathering habits.

9.3 Recommended Research

A primary factor which influenced all those involved in the analyses for this report was the amount of information available. This is illustrated by the fact that there were over 150 independent, potentially useful data elements for each accident.* Thus, the number of potential analyses was enormous. It can only be hoped that the reported analyses represent a reasonable allocation of priorities.

It is clear that many readers will have preferred the inclusion of analyses which do not appear in the findings. It is also clear that there are a plethora of needed analyses which can be conducted with the data available. It is strongly suggested that further exploration of the data be conducted. Some recommendations is this regard follow.

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* Altogether, including different versions of the same data elements, there were over 400 data points per accident.

Impact speed, impact behavior, area of damage, and object struck had profound effects on injury. Furthermore, they were useful in explaining the effects of other factors upon injury. Yet these analyses were quite limited. In particular, these variables were studied singly rather than jointly. It is believed that a much clearer picture of road and roadside effects upon injury could be obtained with a more fully developed model relating impact characteristics to injury. While there currently exist computer simulation methods for doing this, the required inputs depend on trained technicians in the field. In contrast, the results reported herein demonstrate the value of information obtainable by the police, using cameras, with limited special training.

It is believed that such data could be obtained on a large scale, with limited cost, and that the results of appropriate analyses would provide information of extraordinary value. Specifically, the evaluation of current road and roadside factors would reach a level here-to-fore unavailable.

As a first step, it is recommended that the data collected in this study be utilized to develop an analytical process to describe injury-producing mechanisms in terms of these readily collected variables. Included in such a study could be the application of the model to further delineate the effects of road and roadside factors included in the data set.

Another general class of analyses should not be overlooked. This refers to clinical analyses based on the original accident reports. In spite of the volumnous data on magnetic tape, there is a tremendous amount of information in the reports and accompanying photographs which has not been automated. An example, mentioned in the text, pertains to guardrails. While guardrail performance was documented in terms of impact behavior and resultant injury, a review of the individual accidents would provide information pertaining to the nature of structural failure, effects of impact location relative to support posts, guardrail performance in view of shoulder influences, etc. A similar effort could be made with regard to culverts, and to the efficacy of small trees and brush as barriers.

Another important application of this approach relates to road edge effects. Eighteen percent of the accidents were initiated by first departures in which no impact occurred. While there is no record of such departures for which no further impact occurred, it might well be useful to study the effects of road edge characteristics on ensuing accident behaviors. For example, were certain road edge factors conducive to erratic maneuvers when the vehicle returned to the road? Did they induce control problems before the vehicle returned to the road? While this information was not routinely documented, a review of police accident descriptors and photographs could well shed light on this problem.

Finally, there are an almost limitless number of specific analyses which could extend and refine the information reported herein. Some examples follow.

Road alignment was found to influence the generation of accidents, yet reasons for this were largely unexplored. For example, why were downgrades overrepresented as accident locations? Was it primarily a vehicle control problem? Were curve warning signs truly ineffective or were the findings attributable to sign placement at more hazardous locations? Can further study of on-road events such as maneuver and tire mark-related variables help to find a basis for reducing outside departures?

Departure characteristics were shown to be influenced by road factors and, in turn, to influence impact characteristics. Are these relationships in need of further exploration, or do they simply provide understanding but not useful control?

The height and slope of ditches and fill were individually related to event type and injury. Perhaps clearer, more useful, relationships could be derived by analyzing height and slope simultaneously.

Several factors deserve further study regarding the reasons for their influence on injury. Notable among these are pole offset and length of horizontal curve.

Further study is needed on the implied effects of roadside factors upon travel speed.

There was a tendency for vehicles to stay in motion until a rollover or a primary impact occurred. As border offset increased, so did the off-road penetration. Is there a useful roadside remedy for the apparent syndrome of a vehicle chasing disaster?

☆U.S. GOVERNMENT PRINTING OFFICE: 1979-281-568/3

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FCP Category Descripti

1. Improved Highway Design tion for Safety

Safety R&D addresses problem the responsibilities of the F Administration under the Hig and includes investigation of a standards, roadside hardw physical and scientific data of improved safety regulation

2. Reduction of Traffic Improved Operational E

Traffic R&D is concerned w operational efficiency of exi advancing technology, by im existing as well as new facil ing the demand-capacity rel balance through traffic mana such as bus and carpool pref motorist information, and rer

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and ful highway products. toward the com- ost of highway period of main-

Costs, Extend ire Structural

furthering the structural de- d construction ient highways

Implementa-

eveloping and gy into prac- ly identified.

hway Main-

the develop- ology to im- e utilization nal efficiency of highway

* The complete 7-volume official stat available from the National Technica (NTIS), Springfield, Virginia 22161 (price $45 postpaid). Single copies volume are obtainable without ch Analysis (HRD-2), Offices of Resear Federal Highway Administration, Was

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